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ROAD-MAKING STONES.

ATTRITION TESTS
IN THE LIGHT OF PETROLOGY.

— BY —

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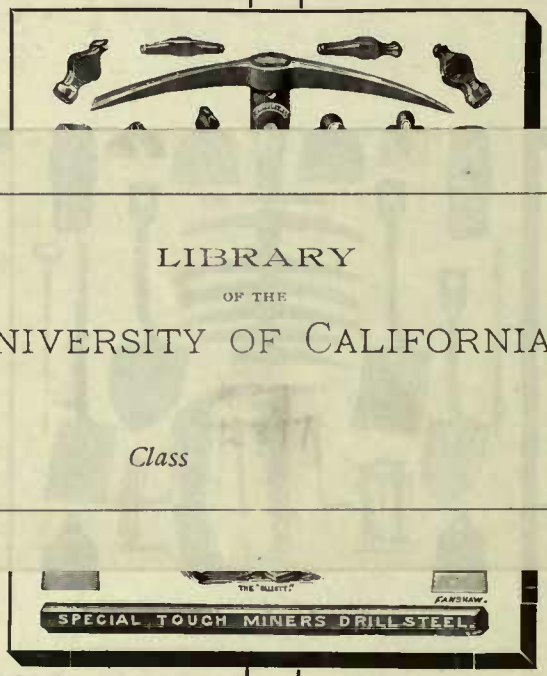
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INTRODUCTION.

The absence of available information as to the comparative value of rocks for road-making purposes led the author to commence in 1895 a series of tests of road stones; a large number of rocks of various classes have now been tested, and it is thought that the results may be of sufficient value to be worthy of being recorded.

The present method of arriving at a conclusion as to the merits of a stone for road-making is the practical one of using a consignment of material and drawing conclusions by observation as to its value. This method, undeniably correct and safe as it may be, can obviously be only of practical service to the person conducting the test or to a limited number of those who are directly interested in the matter in the locality of the trial area; and to record such an experiment is necessarily not of general assistance, as so much depends upon the varying conditions under which the test is made—*viz.*, the subsoil; the character of the foundation of the road; the way in which the existing surface breaks up to receive the new macadam; the gradient of the road; its position in regard to the influence of wind and weather; and last, but not least, the extent and weight of the vehicular traffic, and its effect upon the carriageway, as governed by the width of the track.

The attrition test has hitherto been the most scientific attempt to arrive at a conclusion as to the value of a rock prior to its use as a road stone, and it has been found, from a comparison of the results of such tests with the practical value of the stones in use, that while the test may not be taken as an absolute indication of resistance to road wear, it is a factor of great importance in arriving at a conclusion as to the placement of the material. Neither is the petrological classification of itself a guide; but as a result of the study of the question embracing the attrition test, the texture of the rock, and the practical use of the same, it appeared to the author that a clearer light would be thrown on the subject if the percentage of loss under test were considered in conjunction with the petrological descriptions and photo-micrographs of the material, and that such an investigation should be dealt with in a way that would be of public rather than local service.

On approaching Dr. J. S. Flett, of his Majesty's Geological Survey, and Mr. Allen Howe, the curator and librarian of the Museum of Practical Geology, Jermyn-street, an arrangement was come to by which the tests carried out under the auspices of the Town Council of Hornsey should be submitted to the Geological Survey for examination and report. At a subsequent interview with these gentlemen and the editor of *The Surveyor and Municipal and County Engineer* it was agreed, with the approval of the Director of the Geological Survey and Museum, that specimens and records of tests and examinations should be permanently installed at the museum, the results being duly published. These suggestions were duly submitted to the Board of Education, and sanction was obtained to put them into practice.

In placing the information thus accumulated before the officials of road authorities and others interested in the question generally, it is hoped that the work carried on up to the present time may prove to be the foundation of an authoritative source of reference at his Majesty's Geological Survey and Museum, whence unbiassed and reliable information may be obtained in relation to stones which from time to time are submitted for road-making. Having regard to the large sums of money that are spent upon the highways of Great Britain alone, the careful selection of stones for the varying classes of roads and traffic should result in a considerable saving in local, and therefore national, expenditure. During the progress of the tests and examination some valuable stones have been discovered and their merit recognised prior to the rocks being broken up for quarry purposes. It

would be invidious to name these quarries, but without doubt the results more than justify the work which has been undertaken.

The characteristics of a good road macadam are more complex than would appear to the casual observer, and the fact that a rock may give a high crushing test does not necessarily mean that it is suitable for heavy traffic. The varying qualities of texture have to be considered, and the possibility that deterioration may have set in under the influence of weathering and other agencies.

In comparing the hand *v.* machine broken stone, out of ten tests referred to in the list eight are in favour of the hand-broken method. Assuming, however, that a good mechanical stone-breaker is used, the results, theoretically, depend upon the natural cleavage tendency of the rock; brittle, slaty or schistose rock being the least suitable for this method of breaking. The best rocks are those which possess a tendency towards a cubical fracture.

For purposes of research the percentage of dust or mud produced by the attrition test as compared with the original weight of stone is valuable, as in practice the actual loss in dust represents cash outlay in waste, due to the effect of the wear and tear of the traffic and the grinding action which takes place in the layer of macadam itself. The chips produced may be considered in a measure as an indication of the brittleness (this is particularly noticeable in the case of flints), but regard must be had to the fact that these chips, working into the road, assist in reinstating the fabric of the road crust, and, provided that the rock is fairly tough, a moderately large percentage of chips does not necessarily militate against the practical use of the stone for certain classes of work.

The difference between the result in the wet and dry tests is a probable forecast of the superiority in wet or frosty weather of one stone as compared with another, provided that the samples in question lose approximately equal percentages of dust in the dry tests. These differences, it will be noted, are very varied, only about half the samples of flints giving better results in the wet test, while the whole of the other rocks, constituting the majority, show a loss in the wet test varying from 0 to 282 per cent. above the dry test. The specific gravity is no criterion of quality, and is only recorded as a matter of interest and as a possible guide to freight charges.

The testing apparatus used is shown in the accompanying illustration (Fig. 1), from which it will be seen that the machine consists of three rotating cast-iron cylinders, driven by a gas engine through a countershaft and bevel gearing, enabling three samples of stones to be tested simultaneously. The cylinders are 11 in. internal diameter, with three 1-in. by 1-in. angle-iron ribs, bolted lengthwise in the inside at equal distances apart and parallel to the axis of rotation.

Care has been taken that all samples are subjected to exactly the same conditions of test, and to this end the samples are broken to a 2-in. gauge, as supplied for road work, numbering about sixteen stones and weighing 4 lb. The number of revolutions, recorded by a counter, is confined to 8,000, and the speed to twenty revolutions per minute. In the wet tests the stones are weighed dry, about half a gallon of water being placed in the cylinder, and the weight (after testing) ascertained when the chips and dust have been thoroughly dried again. The chips referred to in the table vary in size, and the largest piece detached from the parent stone, so termed, is taken as not exceeding a weight of $\frac{1}{4}$ oz. The dust produced is in the form of a very fine powder, and the stones, after passing through the test, have the appearance of more or less rounded water-worn pebbles.

The author desires particularly to express his indebtedness for assistance that has been rendered in the work by Mr. A. C. Collis-Adamson, the assistant engineer to the Hornsey Town Council, and to Mr. H. Coombs, who has also rendered practical service.

Samples of all the stones referred to in the list of tests are deposited at the Museum of Practical Geology, where they can be inspected, and reference made to the file recording test and description, and to this extent a Government recording department has already been formed in embryo. From the discussion of the results of the attrition tests, as compared with the microscopic examination of road stones, it may be accepted that the combining of the two processes assists in correcting the slight apparent errors of variation which arise in connection with the former, although these are perceived more in the comparison of closely allied rocks than of distinct classes. While for quarrying variation the test may be regarded as a reliable guide, the objective in general is to produce ultimately a table of comparative values, and this is not practicable unless the various considerations that must be borne in mind as regards price and durability of stone can be reduced to a common basis. The information that has already been obtained and has been submitted for consideration

in the following pages must necessarily be amplified by the testing of additional specimens of rocks, in order to obtain a more conclusive average of the figures representing dust production. There are other conditions to be regarded; for instance, the fracture of the rock, for which a factor of shape should be arrived at, and also the resistance to crushing and the behaviour of stones under the chemical action of road water. The reducing of these conditions to factors of efficiency, which with the market price will enable the road-making value of rocks to be formalised, is a scheme which is well within the scope of scientific work aided by practice.

To perfect the scheme of reference it is apparent that the work of investigation must be continued, and it is most desirable that the whole of the tests should be undertaken and completed by such a Department as his Majesty's Geological Survey, assisted by the practical experience of road stone users.

The value of such a record will readily commend itself, as at present the only guidance available is the experience of each individual user, only to be gained at an expenditure of time and trouble, and by more or less costly experiment without a basis of exact data as to all the considerations to be borne in mind. And with what result? That the individual official ceases to be, and a successor commences *ab ovo* the pursuit of guiding principles by means of wasteful experiment.

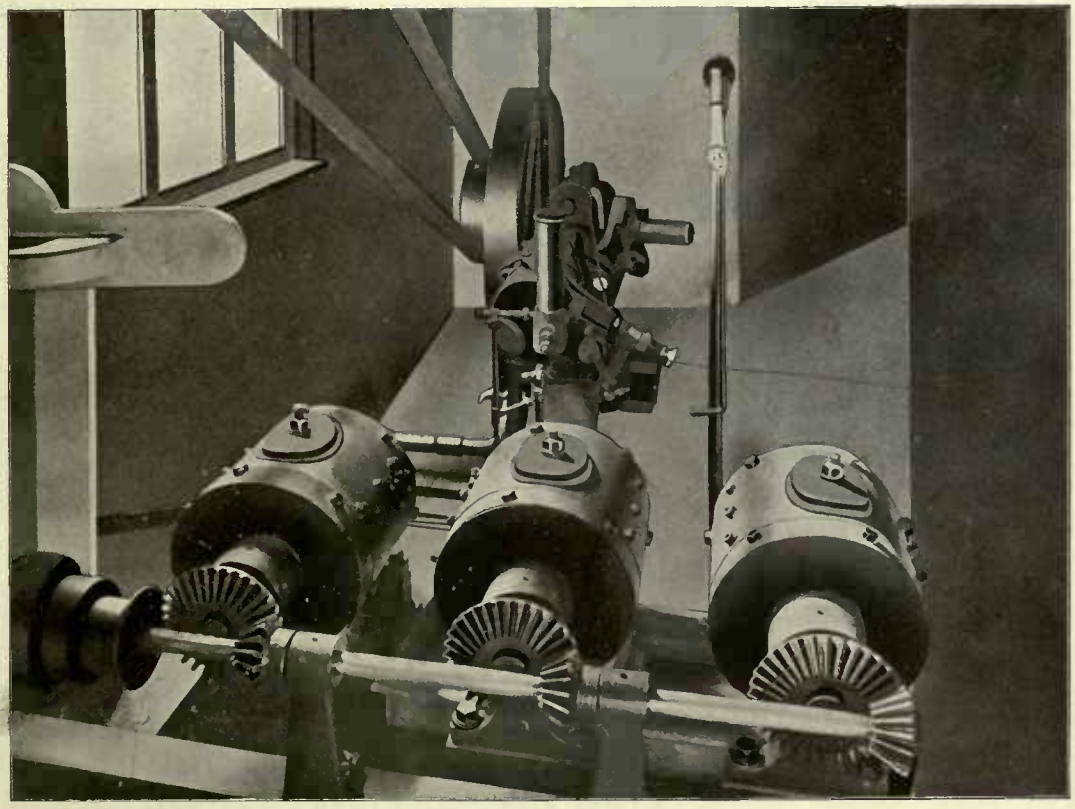


Fig. 1.—Borough of Hornsey Macadam Testing Machine.

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TABLE OF ATTRITION TESTS

OF

ROAD-MAKING STONES.

BY

E. J. LOVEGROVE, M.INST.C.E.,

Borough Engineer and Surveyor of Hornsey.

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TABLE OF ATTRITION TESTS.

Reference number.	Page No.	Description of Stone.	Quarry or locality.	Hand (H) or Machine (M) broken.	Chips. Percentage detached from parent stones. Dry test.	Chips. Percentage detached from parent stones. Wet test.	Dust. Percentage of loss. Dry test.	Dust. Percentage of loss. Wet test.	Dust. Percentage of loss. Average.	Specific gravity.
			PLUTONIC ROCKS.							
13	1	Granite	Ballynacraig Quarry, Newry, Co. Down	H	·0	3·27	9·52	15·87	12·69	2·78
41	3	Biotite-hornblende granite	Mountsorrel, Leicestershire ...	M	1·46	2·98	5·47	7·76	6·61	2·73
77	2	Porphyritic granite	Shap Granite and Patent Concrete Company's Quarries, Westmorland	M	·53	·39	12·94	17·53	15·23	2·65
103	1	Muscovite-biotite granite	Rubislaw, Aberdeen	H	·0	·0	8·39	12·99	10·69	2·70
114	2	„ „	Sclattie Quarry, Newhills, Aberdeen	H	1·02	·0	8·20	11·91	10·05	2·68
4	4	Augite diorite ...	Bush Quarry, Greenore, Co. Louth	M	·0	·14	5·52	9·47	7·49	2·95
15	4	Enstatite-augite diorite	Crown Quarries, Alderney ...	M	·0	·0	7·76	11·67	9·71	2·84
107	3	Hornblende gneiss (1½-in.)	Bordeaux Quarry, St. Sampson's, Guernsey	—	·44	·05	6·78	10·40	8·59	2·86
108	3	Hornblende gneiss (2-in.)	„ „ „	—	1·76	·05	6·15	9·91	8·03	2·86
109	3	Quartz diorite ...	Corvees, Hougue Rowe, Capelles and Romains Quarries, Guernsey	—	3·37	5·07	7·08	12·80	9·94	2·82
18	5	Hornblendic gabbro	St. Sampson's and the Vale Quarries, Guernsey	—	·0	1·37	9·18	12·30	10·74	2·99
116	6	Flaser hypersthene gabbro	Rocks of Balmedie, Belhelvie, Aberdeen	H	·0	·34	8·88	11·86	10·37	2·95
117	6	„ „	„ „ „	H	1·02	·34	7·66	10·50	9·08	2·81
			HYPABYSSAL ROCKS.							
100	9	Granite porphyry...	Narborough Quarry, nr. Leicester	—	·0	·0	3·81	5·66	4·73	2·63
43	10	„ „ ...	Threlkeld, Cumberland	M	·0	·19	6·01	8·98	7·49	2·67
106	9	„ „ ...	Yr Eifl Quarries, Llanaelhaiarn, Carnarvonshire	—	·29	·0	3·91	3·51	3·71	2·65
*14	12	Quartz porphyrite...	Quenast, Belgium	M	·0	·0	2·93	4·54	3·73	2·76
131	11	„ „	Ermitage Quarry, Lessines, Belgium	M	·10	·0	5·27	8·20	6·74	2·74
132	12	„ „	St. Rock Quarry, Lessines, Belgium	M	·19	·78	6·35	6·84	6·59	2·88
5	12	„ „	Narborough, Leicestershire ...	H	·05	·0	4·10	5·47	4·78	2·64
98	10	„ „	Earl Shilton Quarry, Hinckley, Leicestershire	H	·0	·0	4·00	6·69	5·34	2·75
99	10	„ „	„ „ „	M	·0	·0	4·10	7·71	5·90	2·75
73	11	Porphyrite	Mancetter Quarry, Atherstone, Warwickshire	M	·14	2·49	9·96	17·04	13·50	2·80
74	11	Quartz porphyrite...	„ „ „	H	·29	2·39	12·01	17·82	14·91	2·80
97	11	„ „ ...	One mile east of Tavistock, Devonshire	H	·10	·0	7·52	13·57	10·54	2·99
55	14	Felsite	Lindifferon Quarry, Cupar, Fife ...	H	5·12	·78	5·22	5·22	5·22	2·49
115	13	Granophyre ...	Gask Quarry, Skene, Aberdeen ...	H	·83	·14	4·24	5·42	4·83	2·58
119	13	„ ...	Groby, Leicestershire	—	·39	1·96	6·45	12·50	9·47	2·76
*3	20	Olivine diabase ...	Titterstone Quarries, Clee Hill, Ludlow, Shropshire	H	·0	·0	6·00	8·45	7·22	2·91

* For further tests of these rocks see "Supplementary Table of Attrition Tests" (pages 77 to 79).

Table of Attrition Tests.

Reference number.	Page No.	Description of Stone.	Quarry or locality.	Hand (H) or Machine (M) broken.	Chips. Percentage detached from parent stones. Dry test.	Chips. Percentage detached from parent stones. Wet test.	Dust. Percentage of loss. Dry test.	Dust. Percentage of loss. Wet test.	Dust. Percentage of loss. Average.	Specific gravity.
			HYPABYSSAL ROCKS (*continued*).							
7	21	Enstatite porphyrite	Darbishire's Quarries, Penmaenmawr	H	·0	·14	2·44	3·76	3·10	2·73
57	20	Quartz enstatite diabase	„ „ „	—	·0	·0	3·91	7·03	5·47	2·75
88	21	„ „ ...	„ „ „	H	·0	·0	2·54	2·78	2·66	2·74
*71	21	„ „ ...	Brundrit's Quarries, Penmaenmawr	M	·0	·14	4·30	6·78	5·54	2·82
*72	21	„ „ ...	„ „ „	H	·0	·0	2·98	5·17	4·07	2·82
86	22	Porphyritic diabase	Westcott Quarry, Bridford, South Devon	H	1·95	·0	9·28	14·55	11·91	2·53
87	22	„ „	„ „ „	M	·0	.0	8·98	16·79	12·88	2·53
127	24	Diabase	Hill Top Quarry, Dunsford, South Devon	H	·15	·15	5·13	6·69	5·91	2·87
130	25	„	Great Hill Quarry, near Exeter ...	H	·0	·0	2·44	4·39	3·42	2·95
75	24	„	Central Wales Granite Company's Quarries, Llandrindod, Radnorshire	M	·14	2·19	9·52	20·89	15·18	2·68
76	24	„	„ „ „	H	1·12	1·02	9·37	16·94	13·15	2·68
120	23	„	Falcarragh Quarry, Co. Donegal ...	H	1·07	·68	7·13	8·30	7·71	3·06
12	22	„	Rostrevor, Co. Down	M	·0	·0	10·06	13·67	11·86	2·93
56	23	Ophitic diabase ...	Trusham Quarry, South Devon ...	M	·19	·29	10·64	17·28	13·96	2·92
101	24	„ „ ...	Moel-y-Gest Quarries, Carnarvonshire	M	·0	·0	6·74	9·67	8·20	2·94
102	24	„ „ ...	„ „ „	H	3·22	·49	5·76	8·79	7·27	2·94
44	25	Uralitic diabase ...	Meenaweary Quarry, Buncrana, Co. Donegal	H	·0	·0	3·51	5·91	4·71	3·09
45	25	„ „ ...	„ „ „	M	·0	2·00	3·56	6·05	4·80	3·09
46	26	Epidiorite	Ardlough Quarry, near Londonderry	H	2·10	·59	18·80	41·06	29·93	2·76
47	26	„	Fincairn Quarry, near Londonderry	H	·39	3·42	12·50	26·61	19·55	2·85
			VOLCANIC ROCKS.							
*10	14	Trachyte or keratophyre	Coed-y-Glyn Quarry, Glyn, Ruabon, Denbighshire	H	1·02	·44	6·30	7·96	7·13	2·82 to 2·86
50	29	Andesite	Foodie Quarry, Cupar, Fife ...	H	3·66	3·17	9·58	21·78	15·68	2·73
51	29	„	„ „ „	M	2·50	2·54	10·15	22·75	16·45	2·73
54	30	„	Mount Quarry, Cupar, Fife ...	H	2·44	·97	8·44	12·99	10·71	2·67
91	29	„	Dunnimonkshill Quarry, Strathmiglo, Fife	H	·34	·0	5·76	10·30	8·03	2·70
92	29	Biotite andesite ...	Craigowerhouse Quarry, Auchtermuchty, Fife	M	·39	1·66	5·37	6·59	5·98	2·66
1	17	Olivine basalt ...	Linz-on-Rhine	M	·93	·0	7·32	11·47	9·39	3·02
90	17	„ „ ...	Kinnear Quarry, St. Fort, Fife ...	M	1·90	1·61	8·45	18·75	13·60	2·80
*8	20	„ dolerite ...	Clee Hill Dhu Quarries, Clee Hill, Ludlow, Shropshire	H	·0	·0	6·05	10·15	8·10	2·88
6	18	„ „ ...	Whitehead, Belfast	M	·0	·0	10·69	24·85	17·77	2·84
*129	19	Ophitic olivine dolerite	Freehall Quarry, Castlerock, Londonderry	M	·10	·15	9·37	26·90	18·14	2·92

* For further tests of these rocks see "Supplementary Table of Attrition Tests" (pages 77 to 79).

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Reference number.	Page No.	Description of Stone.	Quarry or locality.	Hand (H) or Machine (M) broken.	Chips. Percentage detached from parent stones. Dry test.	Chips. Percentage detached from parent stones. Wet test.	Dust. Percentage of loss. Dry test.	Dust. Percentage of loss. Wet test.	Dust. Percentage of loss. Average.	Specific gravity.
			VOLCANIC ROCKS (*continued*).							
*133	19	Ophitic olivine dolerite	Freehall Quarry, Castlerock, Londonderry, but from top of quarry	M	·15	·0	7·58	16·11	11·84	2·92
48	18	„ „	Blair-Adam, Fife	H	2·05	·0	8·88	14·45	11·66	2·94
49	18	„ „	„ „	M	1·07	·0	9·08	15·62	12·35	2·94
52	18	„ „	Newbigging Quarry, near Ceres, Fife...	H	3·32	·19	10·05	19·63	14·84	2·97
53	18	„ „	„ „ „	M	·0	·0	11·96	21·38	16·67	3·01
93	19	Ophitic dolerite ...	Craigrothie Quarry, Cupar, Fife...	M	1·12	1·17	11·03	42·09	26·56	2·85
			METAMORPHIC ROCKS.							
9	34	Hornfelsed greenstone ("Elvan")	Penlee Quarries, Penzance, Cornwall...	H	1·12	·29	5·42	7·52	6·47	3·02
42	33	Biotite hornfels ("Shap bluestone")	Shap, Westmoreland	M	·24	2·14	6·88	8·98	7·93	2·74
118	33	Cordierite - biotite hornfels	Shiels, Belhelvie, Aberdeen ...	H	·19	·0	5·86	10·25	8·05	2·77
128	34	Diabase hornfels ...	Moonland Quarry, Moreton Hampstead, South Devon	H	·0	·0	5·57	9·86	7·71	2·99
			SEDIMENTARY ROCKS.							
11	38	Quartzite	Hartshill, near Atherstone, Warwickshire	H	·0	·29	6·25	8·35	7·30	2·65
105	37	Ferruginous quartzite	Winford, Bristol, Somersetshire ...	—	·0	·39	3·81	4·98	4·39	2·65
16	38	Quartzite	Cherbourg	H	2·78	·19	5·47	5·95	5·71	2·68
96	38	„	„	H	·29	·93	4·98	8·20	6·59	2·66
83	37	„	Opprebais, Belgium	M	·93	·0	3·42	4·05	3·73	2·65
125	39	Greywacke... ...	Glynrhonwy Slate Quarry, Llanberis, Carnarvonshire	—	·29	·0	10·06	19·82	14·94	2·70
126	39	„	„ „ „	—	·0	·0	7·52	18·26	12·89	2·68
2	39	Sandstone or greywacke	Cleabarrow Farm, Undermillbeck, Bowness-on-Windermere ...	—	·15	·0	6·20	13·38	9·79	2·74
78	42	Micaceous sandstone	Jenkin Quarry, Kendal, Westmoreland	H	·19	·0	4·30	11·42	7·86	2·70
121	41	Sandstone ("brown" paving slab)	Bradford, Yorkshire	H	·0	·0	13·48	27·73	20·60	2·47
122	41	Sandstone ("blue" paving slab)	Hipperholme, Yorkshire	H	·0	·0	12·89	23·92	18·40	2·49
123	41	Sandstone ("white" paving slab)	Between Halifax and Hipperholme, Yorkshire	H	·19	·0	16·41	25·39	20·90	2·48
85	42	Sandstone	Jenkin Crag Quarry, Kendal, Westmoreland	—	1·76	·0	6·54	15·87	11·20	2·73
58	42	Felspathic sandstone	Ingleton, Yorkshire...	—	·10	·92	6·54	10·11	8·32	2·71
111	43	„ „	Gorse's Quarry, Bury, Lancashire	H	1·22	1·03	36·86	53·12	44·99	2·63
112	43	„ „	„ „ „	H	1·76	·63	28·51	50·68	39·59	2·48
113	43	„ „	Leicester Mill Quarry, Chorley, Lancashire	H	·0	2·88	19·92	30·08	25·00	2·53

* For further tests of these rocks see "Supplementary Table of Attrition Tests" (pages 77 to 79).

Table of Attrition Tests.

Reference number.	Page No.	Description of Stone.	Quarry or locality.	Hand (H) or Machine (M) broken.	Chips. Percentage detached from parent stones. Dry test.	Chips. Percentage detached from parent stones. Wet test.	Dust. Percentage of loss. Dry test.	Dust. Percentage of loss. Wet test.	Dust. Percentage of loss. Average.	Specific gravity.
			SEDIMENTARY ROCKS (*continued*).							
110	42	Felspathic sandstone	Houdain Quarries, Calais	—	·15	·0	10·11	13·38	11·74	2·55
30	40	Impure sandstone ("Pennant grit")	Craig-yr-Hesg Quarries, Pontypridd, Glamorganshire	H	·0	·0	14·45	27·54	20·99	2·68
69	40	Impure sandstone	Dee Clwyd, Corwen, Merionethshire	M	1·12	·53	7·66	16·80	12·23	2·75
70	40	„ „	„ „ „	H	·0	·49	9·37	20·75	15·06	2·75
38	45	Calcareous sandstone ("Kentish rag")	Coombe Quarries, Maidstone, Kent	H	·83	·0	16·31	27·44	21·87	2·66
59	44	Calcareous sandstone ("cank")	Scout Bottom, Waterfoot, Lancashire	—	·10	·0	8·01	15·23	11·62	2·71
95	44	Calcareous sandstone ("Bargate limestone")	Liphook Quarries, Hampshire ...	H	·0	·0	9·47	25·17	17·32	2·58
36		Dolomite	Lady Lee Quarries, Worksop, Nottinghamshire	H	·0	4·34	13·23	25·83	19·53	2·70
37	51	Magnesian limestone	Churston Quarry, Torquay, Devonshire	—	5·52	2·00	14·79	29·05	21·92	2·74
39		Dolomite	Chapel Hill and Hangstone Quarries, Clevedon, Somersetshire ...	M	1·22	2·10	8·94	13·33	11·13	2·84
40	51	Dolomite ("rebb stone")	Cattedown Quarry, Plymouth, Devonshire	M	5·42	6·15	16·45	33·64	25·04	2·80
32	50	Crystalline limestone	Walls Hill Quarry, Torquay, Devonshire	—	3·61	7·03	18·36	34·22	26·29	2·71
33	50	„ „	Churston Quarry, Torquay, Devonshire	—	6·49	3·56	16·31	33·64	24·97	2·79
34		„ „	Coombe Quarry, Torquay, Devonshire	—	10·30	5·57	25·59	42·19	33·89	2·81
31		Fossiliferous limestone	Buxton, Derbyshire	H	4·49	2·34	16·26	22·36	19·31	2·72
84	49	Crinoidal limestone	Mont Vireux, France	M	·0	·29	12·89	26·66	19·77	2·69
35	50	Limestone	Barton, St. Mary-Church, Devonshire	H	1·85	3·95	17·53	30·71	24·12	2·71
104	49	„	Winford, Bristol, Somersetshire ...	—	1·85	2·44	13·48	24·71	19·09	2·68
19		Chalk pit flints ...	Grays, Essex	H	2·34	2·73	11·82	9·08	10·45	2·63
26		„ „ ...	Near Thames and Medway, Kent	H	2·78	·39	9·52	6·10	7·81	2·61 to 2·89
21		Pit flints	Longfield, Kent	H	2·34	5·86	9·03	7·37	8·20	2·63
27		Pit flints or coarse gravel	Chalk, near Gravesend, Kent ...	H	15·57	5·12	10·60	10·64	10·62	2·65 to 2·73
63	55	Pit flints	Farnborough, Berkshire	H	4·93	3·41	8·54	8·79	8·66	2·60
64	55	„	„ „ (second test of same stones, after undergoing first test)	—	—	·0	—	3·61	3·61	—
22		Picked surface flints	Ash, near Gravesend, Kent (from heavy, stiff land)	H	5·03	2·78	10·40	10·84	10·62	2·61
23		„ „	Meopham, Kent (from heavy, stiff land, 550 to 700 above O.D.) ...	H	4·30	6·25	10·55	14·89	12·72	2·63
24		„ „	Meopham, Kent	H	2·44	3·03	12·50	14·26	13·38	2·55
25		„ „	Luddesdown, Kent (from chalk hills)	H	1·17	1·95	8·20	7·27	7·73	2·58 to 2·84

Table of Attrition Tests.

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			SEDIMENTARY ROCKS (*continued*).							
65	55	Picked surface flints	Farnborough, Berkshire	H	5·91	3·27	10·98	12·30	11·64	2·76
66	55	„ „	„ „ (second test of same stones, after undergoing first test)	—	—	·11	—	5·20	5·20	—
94	55	„ „	Whitchurch, Hampshire	H	4·44	·0	8·25	6·74	7·49	2·59
20		"French burr" ...	France (chips from manufacture of cement-grinding millstones) ...	H	1·17	2·29	6·79	7·81	7·30	2·58
			ARTIFICIAL STONES.							
28		Iron slag	Wellingborough	M	·0	1·32	8·20	14·40	11·30	3·02
29		„	Kettering	H	·0	·0	8·01	14·35	11·18	2·91
80		Artificial York stone	—	H	2·34	·73	20·21	45·26	32·73	2·39
81		Clinker paving slab	Hornsey destructor	H	·29	1·76	15·33	36·23	25·78	2·52
82		Granitic paving slab	—	H	·24	1·12	22·02	46·14	34·08	2·57

NOTE.—For "Supplementary Table of Attrition Tests," see page 77.

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No. 13.

GRANITE.

BALLYNACRAIG QUARRY, NEWRY, CO. DOWN.

"A grey granitite, without muscovite, but with quartz, two felspars, black mica, and greenish hornblende. Much plagioclase felspar, probably oligo-

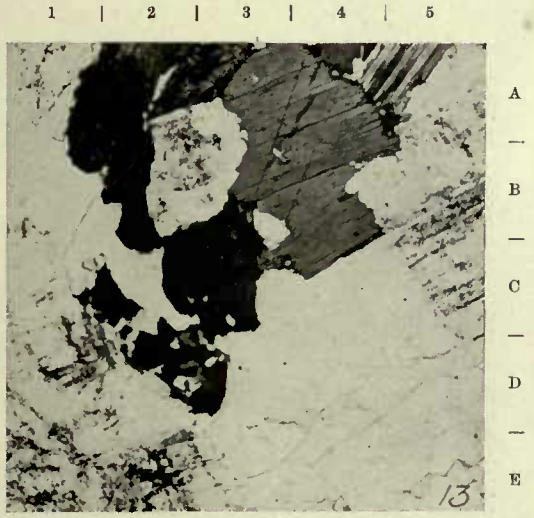


FIG. 2.

clase, is present; and this sometimes increases in quantity so much that, though normally a potash granite, the mass locally becomes a *soda granite*. Sphene and apatite are abundant, and the mica is so much altered to chlorite as to look green in the hand specimen."—Prof. W. W. Watts, "Guide to the Collections of Rocks and Fossils belonging to the Geological Survey of Ireland," Ed. 1, p. 75.

It is a light grey stone speckled with black. The quartz and white felspar and black shining plates of mica are all easily seen in the hand specimen, as well as occasional bits of dark green, almost black, hornblende.

The appearance of this stone under the microscope is shown in Fig. 2; the white masses are quartz, the cloudy grey masses, A-B-C 5 and C-D-E 1, are felspar; most of the dark minerals are black mica, but in A 3-2 is a crystal of sphene, and the dark piece in D 2 is green hornblende; the short rectangular white prism touching the lower side of the latter is apatite.

Attrition Test No. 13.

Loss per cent.	Dry test	9·52
	Wet test	15·87
	Average	12·69

No. 103.

MUSCOVITE-BIOTITE GRANITE.

RUBISLAW, ABERDEEN.

A grey medium-grained muscovite-biotite granite, which occasionally shows a rude and elementary foliation. Its principal constituents are quartz, orthoclase, microcline, oligoclase, muscovite, and

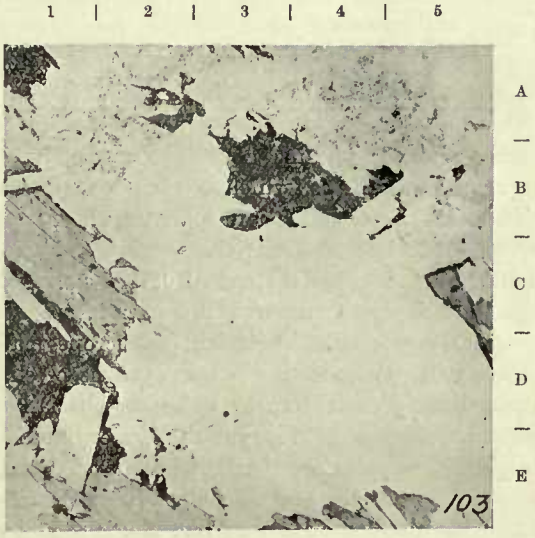


FIG. 3.

biotite; it contains also apatite, zircon, and iron oxides. Of the felspars, microcline is most abundant, and forms large irregular crystals, which enclose small rounded areas of quartz and other materials. The quartz contains fluid cavities and

small dark hairs of rutile. It is often slightly granulitic, and the other ingredients also sometimes show slight effects of crushing. Muscovite is abundant, and usually occurs in clusters mixed with biotite; the two may sometimes be in parallel growth. The biotite is dark brown, and contains enclosures of apatite and zircon. Idiomorphic oligoclase, orthoclase, and rounded patches of vermicular micropegmatite, are also present in considerable quantity.

It is not possible to show all the features of this stone in a small photomicrograph taken by ordinary light, but the following may be noticed in Fig. 3: The large plate of quartz (white), the slightly clouded felspar A 1-2 and A-B 4-5; the black mica in various dark shades, B-C-D 1, E 3-4, A-B 3-4; the white bars penetrating the black mica are white mica (muscovite); the broad white rectangle, D-E 1, is felspar enclosed in biotite.

Attrition Test No. 103.

Loss per cent.	Dry test	8·39
	Wet test	12·99
	Average	10·69

No. 114.

MUSCOVITE-BIOTITE GRANITE.

Sclattie Quarry, Newhills, Aberdeen.

This granite contains abundant microcline, in large irregular plates, which envelop many of the other constituents. Other felspars are also present, chiefly orthoclase and oligoclase. Muscovite and biotite are both common, usually aggregated together. Apatite, zircon, and iron oxides are the principal accessories. Vermicular micropegmatite forms small sponge-shaped masses. Signs of slight crushing by pressure are to be seen, especially in the quartz, which often is granulitic, or extinguishes irregularly in polarised light. The quartz contains lines of fluid cavities and thin black hairs of rutile.

The hand specimen is very like No. 103, and the micro-section closely resembles Fig. 3.

Attrition Test No. 114.

Loss per cent.	Dry test	8·20
	Wet test	11·91
	Average	10·05

No. 77.

PORPHYRITIC GRANITE.

Shap Granite and Patent Concrete Company's Quarries, Westmoreland.

The well-known Shap granite is porphyritic; that is, certain constituents—in this case some of the felspars—having crystallised out before the others, they have a more perfect form. It contains large (porphyritic) flesh-coloured felspar (both orthoclase and plagioclase), large rounded quartz grains, and plates of biotite in a matrix of crystalline quartz and felspar. The biotite is weathering to chlorite; there are also many crystals of iron ores, sphene and apatite; also a little zircon and

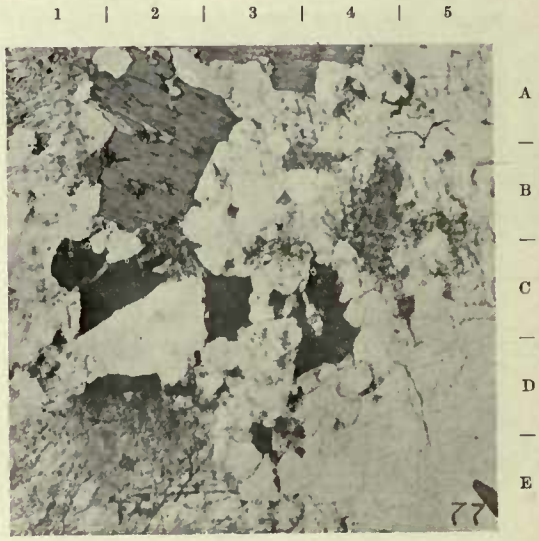


Fig. 4.

grains of pyrites. As the felspar is red and slightly turbid, it is easily distinguished in the hand specimen from the clear, glassy quartz and black, shining biotite. Fig. 4 brings out most of these points; it shows the clear quartz, D-E 4-5, and turbid felspar, and the plates of biotite, A 2-3-4, and C 2-3-4; only a portion of a larger felspar crystal is seen, E 1-2. The pale streaks in the biotite, A 2, are chlorite. See Harker's "Petrology," Third Edition, p. 37, and Teall's "British Petrography," plate 35, No. 1.

Attrition Test No. 77.

Loss per cent.	Dry test	12·94
	Wet test	17·53
	Average	15·23

No. 41.

BIOTITE-HORNBLENDE GRANITE.

Mount Sorrel, Leicestershire.

A rather fine-grained dull red stone. On a newly-fractured surface it is easy to make out the dull red felspar, the green chlorite, and dark grains of hornblende; clear, shining quartz can be seen between the other mineral grains.

The felspar is decomposed and stained red. It occurs partly in small porphyritic crystals, Fig. 5, B-C 3, and partly in much smaller crystals, forming a ground mass with quartz. The dark minerals are biotite (weathered to green chlorite), C-D 4, and greenish brown hornblende, A-B 1-2. A good deal of the felspar is plagioclase. The quartz is all in

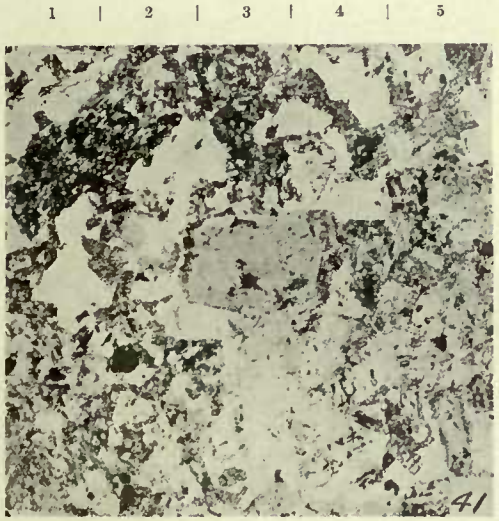


Fig. 5.

the ground-mass, and is the last ingredient to crystallize, as it encloses the latest felspars.

See Teall, "British Petrography," p. 321; Hill & Bonney, Q.J.G.S., vol. xxxiv. (1878), p. 218; Harker, "Petrology," Third Edition, p. 38.

Attrition Test No. 41.

Loss per cent.	Dry test	5·47
	Wet test	7·76
	Average	6·61

Nos. 107 and 108.

HORNBLENDE GNEISS.

Bordeaux Quarry, St. Sampson's, Guernsey.

Both this and the following are more generally included among the varieties of "Blue Guernsey Granite." It consists of green hornblende in irregularly-shaped masses, a little weathered biotite, orthoclase and plagioclase felspar, and quartz. The structure is gneissose, but approaches granitic in some parts of the slide. Effects of crushing are seen, especially in the quartz. The iron ores may

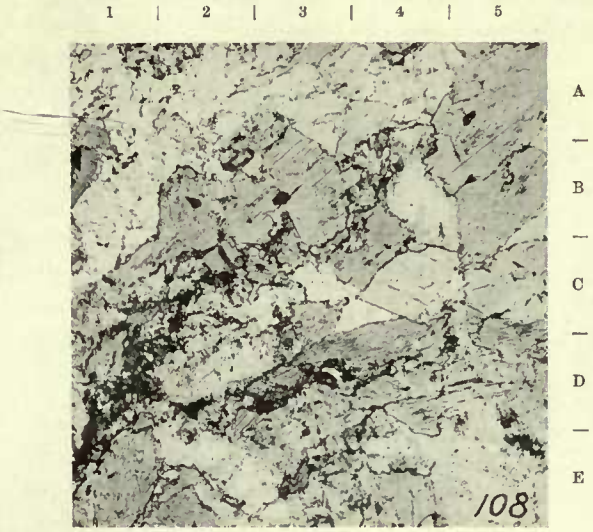


Fig. 6.

"Blue Guernsey Granite."

be surrounded with granular sphene. The only constituents which show idiomorphism are the felspars, occasionally, and the apatite.

It is a dark bluish-green stone of medium grain and crystalline texture; the white grains of felspar and quartz and the green ones of hornblende are easily distinguished by the unaided eye.

The predominance of hornblende is noticeable in Fig. 6, where all the grey-shaded portions represent this mineral, A-D 5. The paler portions are either felspar, D 2, B 4, or an aggregate of quartz and felspar grains, A 1-4.

Attrition Test No. 107.

Loss per cent.	Dry test	6·78
	Wet test	10·40
	Average	8·59

No. 109.

QUARTZ DIORITE.

Corvees, Hougue Rowe, Capelles and Romains Quarries, Guernsey.

Dark green hornblende and dark brown biotite are about equally common in this rock; plagioclase

felspar and quartz are the other important constituents. The two former minerals are black in the hand specimen; the felspar is grey, the quartz is clear and not very obvious. The hornblende and biotite sometimes enclose the felspar, but usually

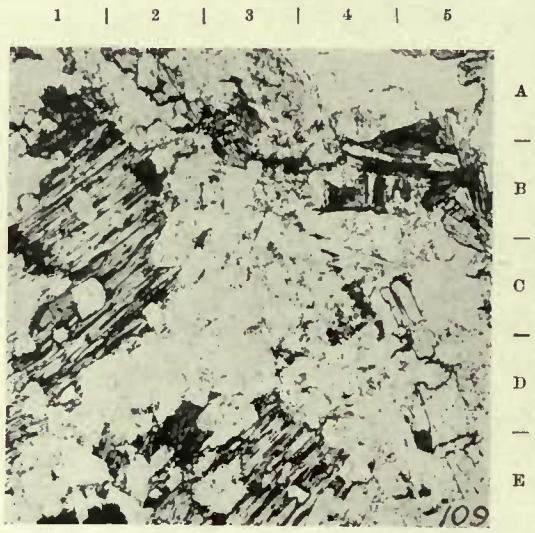


Fig. 7.

these three minerals have well-formed crystals. Orthoclase is present in small quantity; also iron oxides, apatite, and zircon. The structure of the rock is massive, and is typical of diorites, except that the quartz shows occasionally slight effects of strain.

In the hand specimen and under the microscope this stone is of somewhat coarser grain than No. 108.

The dark streaky plates in Fig. 7 are biotite; the pale rectangular outlines in C-D-E 4-5 are green hornblende; the whitest portions are quartz mixed up in an irregular way with clouded felspar, which occupies nearly all the lighter parts of the figure.

Attrition Test No. 109.

Loss per cent.	Dry test	7·08
	Wet test	12·80
	Average	9·94

No. 4.

AUGITE DIORITE.

Bush Quarry, Greenore, Co. Louth.

Known locally as "Blue Granite." The rock has rather a pale green colour in the hand specimen, with a dull appearance and even texture, and is obviously not entirely fresh. It consists principally of plagioclase felspar, which is turbid from decomposition, and of green, fibrous and uralitic hornblende, which seems to be mostly secondary after pyroxene. A little pale-green augite is visible in the section, altering to uralite. Primary hornblende is probably absent, but there is a fair quantity of dark brown biotite, D 4. Patches of quartz and of micropegmatite occur in the slide, but are not important. There are also large crystals of iron-oxide, B 2, and secondary granular sphene. Chlorite, epidote and calcite are all present, and have resulted from the decomposition of the other minerals.

In Fig. 8 most of the darker parts represent

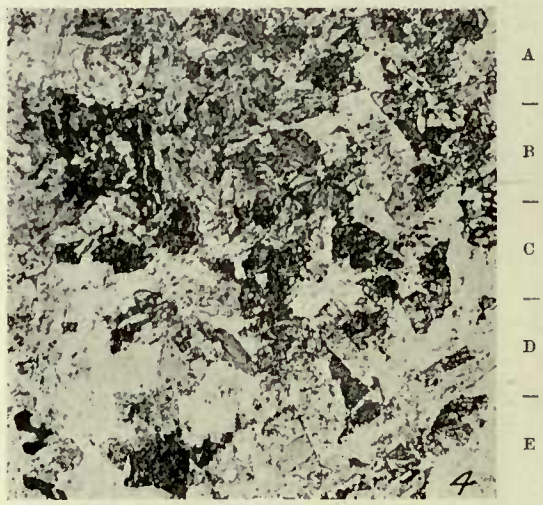


Fig. 8.

uralite and epidote, the remainder is cloudy felspar, with quartz in the whitest patches.

Attrition Test No. 4.

Loss per cent.	Dry test	5·52
	Wet test	9·47
	Average	7·49

No. 15.

ENSTATITE-AUGITE DIORITE.

Crown Quarries, Alderney.

A dark green stone of medium grain, rather coarser than No. 4, speckled with white; it consists of plagioclase felspar, augite, and enstatite.

The plagioclase occurs in crystals, which are frequently turbid by decomposition, and though often idiomorphic, are not enclosed in the augite in ophitic fashion. The augite is clear brown, and shows frequently, in addition to the pyroxene cleavage, the lamellar structure of diallage. It is

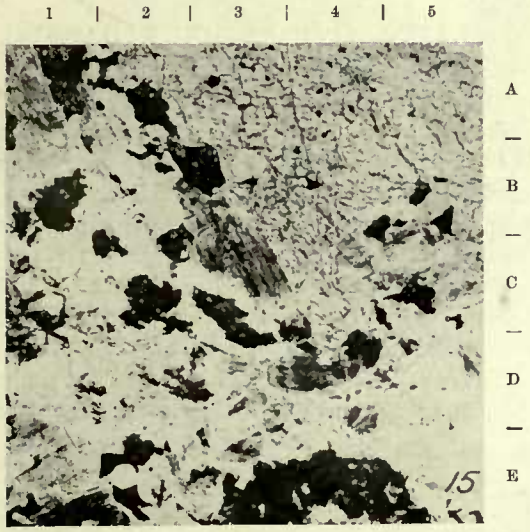


Fig. 9.

very fresh, and contrasts strongly in this respect with the enstatite, which has been converted almost entirely into masses of platy green bastite. The enstatite is usually in sharply-formed crystals; the augite is also idiomorphic at times, though, as a whole, less regularly outlined than the enstatite. A little hornblende may be seen intergrown with the augite. Iron ores are frequent. Apatite is also present.

In Fig. 9, at A-B 3-5, a portion of a large crystal of augite is shown; the cloudy masses, A 1, C 3, and D 3-4, are the crystals of enstatite converted to bastite; the clear patches represent fresh felspar. Some of the dark patches, such as A 1, B 2, E 2, represent iron ores, but the majority of the others, such as A 2, E 2-3, B 1, are opaque decomposed felspar.

Attrition Test No. 15.

Loss per cent.	Dry test	7·76
	Wet test	11·67
	Average	9·71

No. 18.

HORNBLENDIC GABBRO.

St. Sampson's and The Vale Quarries, Guernsey.

In the hand specimen this is a dark grey crystalline rock, with large irregular individuals of hornblende in a granular matrix. The section shows that the rock consists principally of plagioclase felspar in short, rounded individuals, and of clear, pale-brown augite in crystals, which are sometimes, though not usually, idiomorphic. The felspar and the pyroxene are both schillerised in places, and the augite has not unfrequently the platy structure of diallage. No olivine is present, but there are many large crystals of hornblende, dark green in colour, enclosing plagioclase felspars in an ophitic manner. This hornblende may be intergrown with the diallage either in scattered patches or as a border on its surfaces. Iron ores and apatite are also present, and there are a few bastite pseudomorphs, apparently after idiomorphic enstatite. The structure of the rock is rather that of the gabbros than of the diorites.

The large dark mass in the lower part of Fig. 10 is a crystal of green hornblende; the white bodies

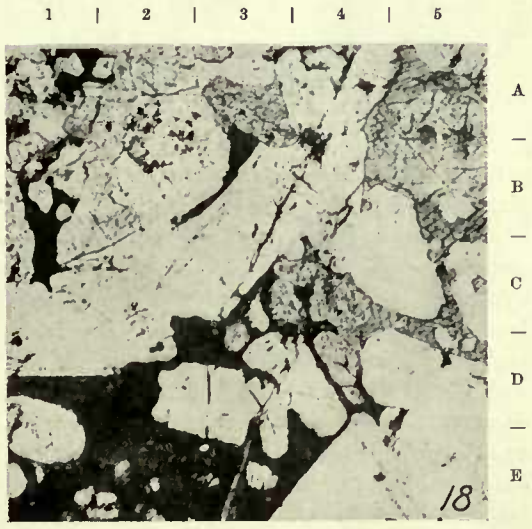


Fig. 10.

enclosed in it are crystals of felspar. The dark grey cross-hatched mineral in B-D 5 is also hornblende; the paler grey material seen in the figure is augite; the black bodies in A-B 1, and in B 3, are iron ores. All the clear parts are felspar.

Attrition Test No. 18.

Loss per cent.	Dry test	9·18
	Wet test	12·30
	Average	10·74

No. 116.

FLASER HYPERSTHENE GABBRO.

ROCKS OF BALMEDIE, BELHELVIE, ABERDEEN.

A dark grey stone, with a well-marked shininess on the freshly-fractured surface. The main com-



FIG. 11.

ponents of this rock are diallage, hypersthene, and plagioclase felspar. The diallage is brownish, and, in addition to the usual prismatic cleavages, has the platy structure characteristic of this mineral; the hypersthene has a distinct pleochroism, ranging from pink to clear green; the plagioclase is schillerised and filled with small opaque enclosures. The rock contains also a little biotite and iron oxides; decomposition products are rather abundant, such as chlorite and bastite. Flaser structure has been developed by crushing, and belts of broken material traverse the section, but there has been no considerable formation of new minerals at the expense of the old.

In Fig. 11 large plates of diallage are seen at A-B 4-5, and C-E 3. Hypersthene is represented in B 2 and C 3-4. The clear white patches are all plagioclase felspar; the black masses are iron ores. A little biotite is visible in B 3, touching the upper end of the central felspar crystal.

Attrition Test No. 116.

Loss per cent.	Dry test	8·88
	Wet test	11·86
	Average	10·37

No. 117.

FLASER HYPERSTHENE GABBRO.

ROCKS OF BALMEDIE, BELHELVIE, ABERDEEN.

Somewhat coarser-grained and more felspathic than the previous rock, but essentially of the same kind. It also is crushed, and a little sphene has been produced from the iron oxides and some acicular actinolite from the ferro-magnesians. The large plates of diallage are curved and distorted, and the felspar begins to assume the character of a granulitic mosaic.

The whole of Fig. 12 is occupied by grains of felspar, except under A-B-C 5, where the extremity

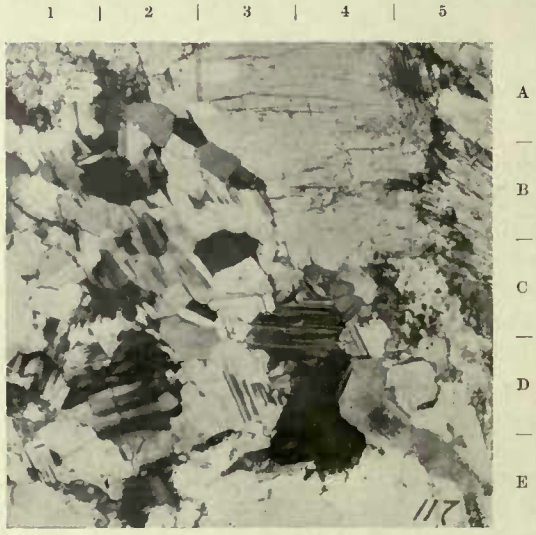


FIG. 12.
(*Photographed in polarised light.*)

of a large plate of diallage is seen. The striped appearance of the felspar is due to its having been photographed in polarised light.

Attrition Test No. 117.

Loss per cent.	Dry test	7·66
	Wet test	10·50
	Average	9·08

THE PORPHYRY AND PORPHYRITE GROUP,

INCLUDING FELSITES, GRANOPHYRES AND TRACHYTES.

In this group is gathered a number of rocks which differ from those previously considered by the possession of either a uniformly finer texture or a fine-grained groundmass, in which one or more minerals appear to stand out prominently by virtue of their large size. Such crystals, which have formed before the rest of the material has crystallised, are called "phenocrysts," or are said to be "porphyritic"; they may be quartz (Nos. 45 and 131), felspar (Nos. 98 and 106), or one or other of the ferro-magnesian minerals.

As regards their chemical composition, most of the stones included here would differ very little from the granites and diorites.

The variety known as Granophyre is characterised by a close intergrowth of the felspar and quartz (No. 119); this granophyric or micrographic structure may occur only in patches, or may be the dominant structure throughout the rock.

The porphyries are characterised by predominant orthoclase felspar, the porphyrites by plagioclase.

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THE PORPHYRY AND PORPHYRITE GROUP.

No. 100.

GRANITE PORPHYRY.

NARBOROUGH QUARRY, LEICESTER.

This rock contains red orthoclase felspar, both as porphyritic crystals and in a fine ground-mass mixed with quartz. Biotite has also probably been

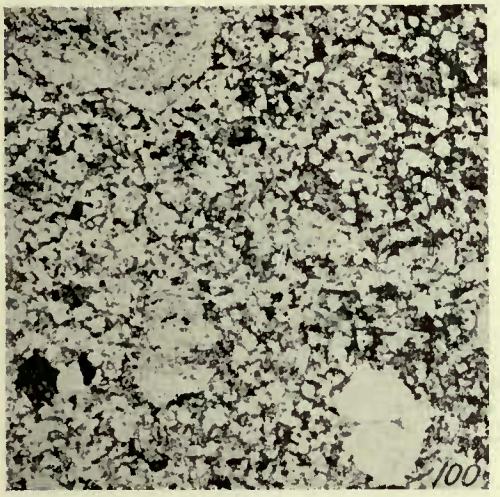


FIG. 13.

present, but has been replaced by chlorite, &c. Iron ores and apatite are the accessories. There are a few small phenocrysts of quartz. The ground-mass is mostly microgranitic, but in places is micrographic. The stone is pinkish-red, with green specks (chlorite).

At the top left-hand corner of Fig. 13 a portion of a large porphyritic felspar is visible; the white body in the opposite lower corner is a crystal of quartz, and all the small white grains in the ground-mass are felspar; and, with the exception of a few elongated dark flakes of chloritised biotite, the black spots are iron oxides.

Attrition Test No. 100.

Loss per cent.	Dry test	3·81
	Wet test	5·66
	Average	4·73

No. 106.

GRANITE PORPHYRY.

YR EIFL, LLANAELHAIARN, TREVOR QUARRIES, CARNARVON.

This rock is light grey in colour, with the porphyritic felspars slightly tinged with pink. These felspars vary in size up to a quarter of an inch in diameter; there is no porphyritic quartz, and dark scales of chloritised biotite are scattered abundantly through the rock. Under the microscope the large felspars show the characters of orthoclase and oligoclase. They are sharply formed, though their margins are sometimes a little irregular, and they are mostly sufficiently fresh to show the characteristic twining and other microscopic structures of these minerals. Often they are cloudy and dull, with a fine deposit of kaolin, muscovite, calcite, and epidote, due to incipient decomposition.

The black mica (biotite) visible in the hand specimen is nowhere altogether fresh, but is

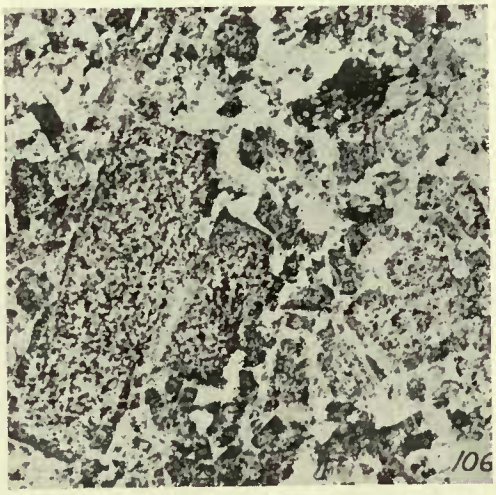


FIG. 14.

changing to chlorite, mixed with calcite, limonite, and other secondary products. The fine-grained ground-mass in which the larger felspars lie is not very conspicuous when the rock is examined with the naked eye, but is obvious in the microscopic slide. It consists of orthoclase and plagioclase

felspar, with clear quartz, and is sometimes micrographic and at other times micrographic in structure. A few grains of zircon, apatite, and iron ores, are present, the latter weathering to sphene; and epidote, limonite, and calcite are also observable. One small crystal of green hornblende occurs in the slide.

In Fig. 14 two large porphyritic crystals of felspar are seen lying side by side; their spotty appearance is due to the partial decomposition, as already explained. The white portions of the figure represent quartz; the dark mass near the upper right-hand corner is chloritic biotite.

Attrition Test No. 106.

Loss per cent.	Dry test	3·91
	Wet test	3·51
	Average	3·71

No. 43.

GRANITE PORPHYRY.

THRELKELD, CUMBERLAND.

Large crystals of quartz and of felspar lie scattered through a matrix of smaller grains of the same minerals. All the felspar is turbid and semi-

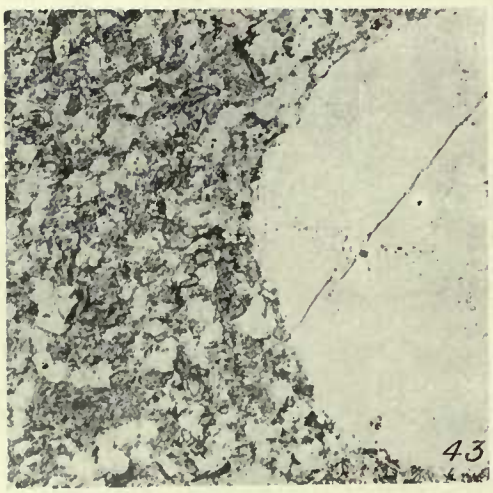


FIG. 15.

opaque, through weathering. There have been also large and small biotite crystals, but these have altered to chlorite. Secondary muscovite has formed through the rock, as a product of the decomposition of the original felspar.

The relative size of the quartz crystals and the ground-mass is clearly shown in Fig. 15; neither the muscovite nor the large porphyritic felspar is included in the view. The grey portion of the ground-mass is felspar, the clear white is quartz. A number of small flakes of chloritised biotite may be observed about the centre of the figure.

Attrition Test No. 43.

Loss per cent.	Dry test	6·01
	Wet test	8·98
	Average	7·49

Nos. 98 and 99.

QUARTZ PORPHYRITE.

EARL SHILTON QUARRY, HINCKLEY, LEICESTER.

This is generally known as "Blue Leicester Granite," Nos. 5 and 100 being the "red" variety.

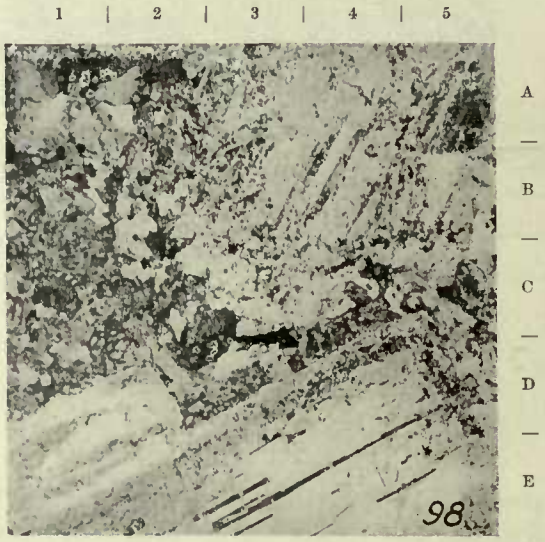


FIG. 16.

(Photographed in polarised light.)

It consists mostly of plagioclase felspar with a little interstitial quartz. It contains also a small amount of pale brown hornblende (together with apatite, iron ores, and secondary products such as chlorite). The structure is porphyritic, and the rock is to be placed among the quartz porphyrites. See Teall's "British Petrography," p. 271.

Most of Fig. 16 is occupied by two large crystals of felspar, A-C 3-5 and D-E 1-5, showing the characteristic twin laminæ; in the remainder of the field, cloudy felspar and a few clear grains of quartz constitute the ground-mass. The dark spot, D 2-3, is a hole in the slide, but the one to the right of it is iron oxide. The mass in A 1, partly

black and partly grey, is green chlorite. The dark-grey irregular grains in C 2 are epidote.

Attrition Test No. 98.

Loss per cent.	Dry test	4·00
	Wet test	6·69
	Average	5·34

No. 97.

QUARTZ PORPHYRITE.

One Mile East of Tavistock, Devon.

A brownish-green igneous rock, which may, perhaps, be classed among the porphyrites. It con-

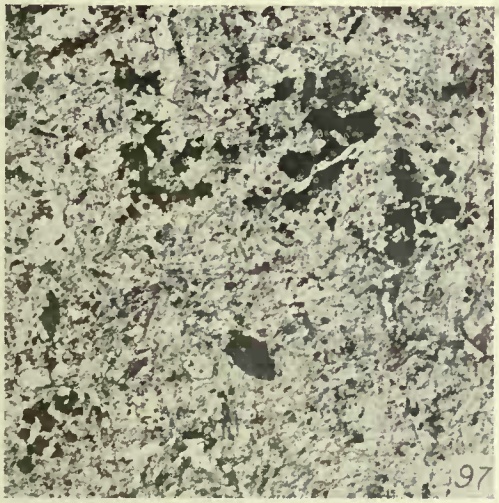


Fig. 17.

tains phenocrysts of plagioclase felspar and of pale augite in a ground-mass of felspars with a little quartz. Iron oxides and apatite also occur, and there is secondary epidote and chlorite after the ferro-magnesian minerals.

The photomicrograph, Fig. 17, gives a good idea of the matted felspars of the ground-mass, but neither the felspar nor the augite phenocrysts are shown. About half the black specks are epidote; the others are iron oxides. Some of the clear grains are quartz and the others are chlorite.

Attrition Test No. 97.

Loss per cent.	Dry test	7·52
	Wet test	13·57
	Average	10·54

Nos. 73 and 74.

PORPHYRITE.

Mancetter Quarry, Atherstone, Warwickshire.

A porphyrite (locally termed a "Greenstone"), apparently vesicular, and full of calcite, chlorite, and other secondary products. Elongated crystals of plagioclase felspar crossing one another in all directions form the greater part of the rock. The ferro-magnesian minerals are entirely decomposed. Patches of zeolites are frequent. There are also iron oxides, changing to leucoxene, and small prisms of apatite.

The thin section of the rock is similar to that of No. 97, with the difference that in these stones the large phenocrysts are not recognisable and the ground-mass is finer in texture. The presence of vesicles filled with secondary minerals is a prominent feature.

Attrition Test No. 73.

Loss per cent.	Dry test	9·96
	Wet test	17·04
	Average	13·50

No. 131.

QUARTZ PORPHYRITE.

Ermitage Quarry, Lessines, Belgium.

A brown stone, covered with spots of pale and dark green. This is a quartz-diorite porphyrite very

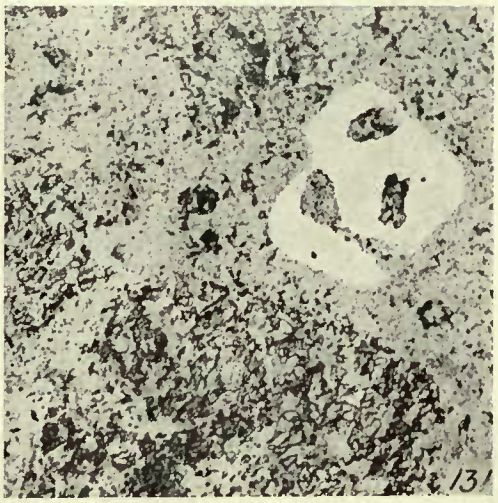


Fig. 18.

like the well-known rock from Quenast (No. 14). It has a fine microgranitic matrix, consisting of quartz and felspar, filled with epidote, chlorite, and

other secondary minerals. In this lie many turbid and weathered crystals of felspar, usually charged with granular epidote and chlorite, which stain them green. There are also a few rounded, much corroded crystals of quartz, also pseudomorphs, in chlorite and sagenitic rutile after biotite or some other ferro-magnesian mineral. Other ingredients are small crystals of apatite, iron oxides and zircon.

In Fig. 18 the rectangular outline of one of the porphyritic felspar crystals is seen in the lower portion; the corner of another one appears on the left-hand side. The irregular granules with dark borders within these two felspars are epidote. The microgranitic matrix occupies the remainder of the space, except where the clear crystal of corroded quartz lies.

Attrition Test No. 131.

Loss per cent.	Dry test	5·27
	Wet test	8·20
	Average	6·74

No. 132.

QUARTZ PORPHYRITE.

St. Rock Quarry, Lessines, Belgium.

A green stone with pale yellowish-green and dark green spots. Similar in all essential points of structure and mineralogical composition to the last. The porphyritic ingredients are not quite so abundant, and there is a great amount of secondary epidote. See Fig. 18.

Attrition Test No. 132.

Loss per cent.	Dry test	6·35
	Wet test	6·84
	Average	6·59

No. 14.

QUARTZ PORPHYRITE.

Quenast, Belgium.

This rock is a good deal decomposed, and contains in a fine micro-granitic matrix of quartz and felspar many large weathered phenocrysts of felspar and of ferro-magnesian minerals. These last are represented by aggregates of chlorite and epidote. The felspars also are full of epidote grains. There are occasional porphyritic crystals of quartz, which are much corroded. The iron oxides are weathering to leucoxene. Secondary muscovite occurs in the felspars. See Fig. 18, which it resembles.

The hand specimen is very similar to No. 131, but the flesh-coloured porphyritic felspars and dark green decomposed ferro-magnesian minerals are rather larger than in that stone.

Attrition Test No. 14.

Loss per cent.	Dry test	2·93
	Wet test	4·54
	Average	3·73

No. 5.

QUARTZ PORPHYRITE.

Narborough, Leicestershire.

"It consists of more or less decomposed plagioclase crystals, corroded quartz grains, green decomposition products after the ferro-magnesian

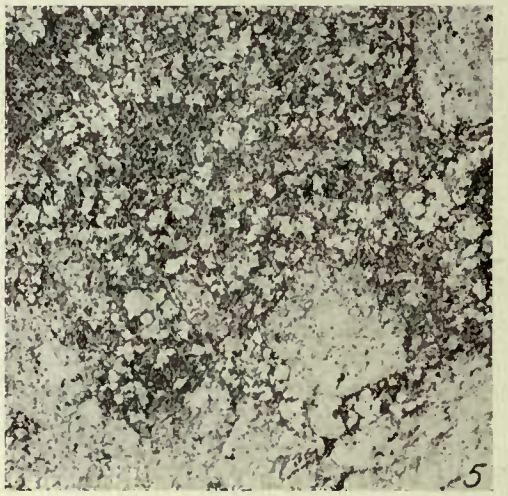


Fig. 19.

minerals, magnetite or ilmenite, and a microcrystalline mosaic of quartz and turbid felspar which constitutes the ground-mass. The porphyritic felspar appears to be wholly plagioclase."—J. J. H. Teall, "British Petrography," p. 271.

In the hand specimen it is pink or light red, and shows well the small porphyritic felspars (rather darker red) and green spots of chlorite and other secondary minerals.

Portions of larger felspar crystals lying in a matrix of micro-granitic felspar and quartz are shown in Fig. 19; the felspar of the ground-mass appears dark through its being very turbid and stained red.

Attrition Test No. 5.

Loss per cent.	Dry test	4·10
	Wet test	5·47
	Average	4·78

No. 115.

GRANOPHYRE.

GASK QUARRY, SKENE, ABERDEEN.

A red stone similar in appearance to No. 5; the larger individuals of quartz and felspar can easily



FIG. 20.

be seen in the hand specimen. It is a granophyre, showing porphyritic crystals of quartz and of felspar. The felspar is mostly a turbid orthoclase, and many of the phenocrysts are graphic or sub-graphic groups of quartz and felspar. The ground-mass is coarsely granophyric. There are a few scales of muscovite scattered through the ground-mass. Iron ores and apatite occur as accessories.

The lower part of Fig. 20 is occupied by a group of large quartz and felspar crystals, with a marked tendency to graphic structure, on its outer borders. The quartz is corroded and the felspar is turbid. The upper part of the figure is filled with the typically granophyric ground-mass of quartz and felspar.

Attrition Test No. 115.

Loss per cent.	Dry test	4·24
	Wet test	5·42
	Average	4·83

No. 119.

GRANOPHYRE.

GROBY, LEICESTERSHIRE.

The red patches in the hand specimen of this rock are a fine intergrowth of quartz and felspar (micropegmatite), in which the other ingredients are embedded. The green streaks are chlorite, iron ores, and epidote, after some ferro-magnesian mineral which can no longer be recognised. Larger well-shaped porphyritic crystals of felspar lie scattered through the rock, they are visible in the thin slice; they include both orthoclase and plagioclase, but are often much weathered. Quartz very rarely forms definite areas of any size, being almost altogether in small angular patches in the felspar of the ground-mass.

All the upper part of the photomicrograph, Fig. 21, is occupied by the intimate graphic intergrowth of felspar and quartz; the individual elements are finer above and become coarser below. The dark masses, B 4 and D 4, are alteration products of the felspar; the black masses, D 1 and E 5, are green ferro-magnesian minerals. The grey rectangular crystal in E 1 is one of the porphyritic

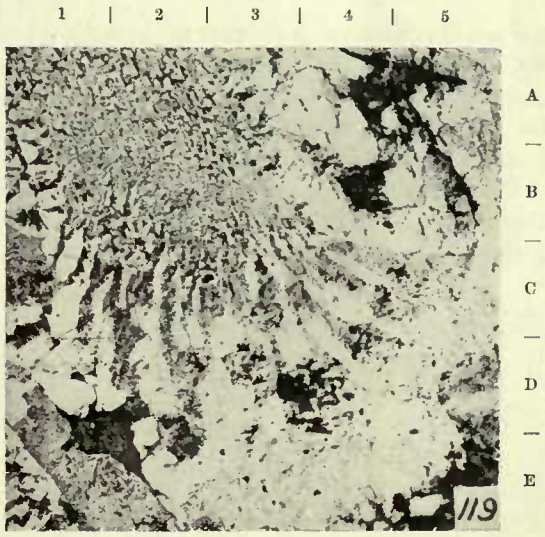


FIG. 21.

felspars. This stone is coarser in grain than No. 115.

Attrition Test No. 119.

Loss per cent.	Dry test	6·45
	Wet test	12·50
	Average	9·47

No. 55.

FELSITE.

LINDIFFERON QUARRY, CUPAR, FIFE.

This is a fine-grained bright red stone, with alternately lighter and darker bands; it is banded

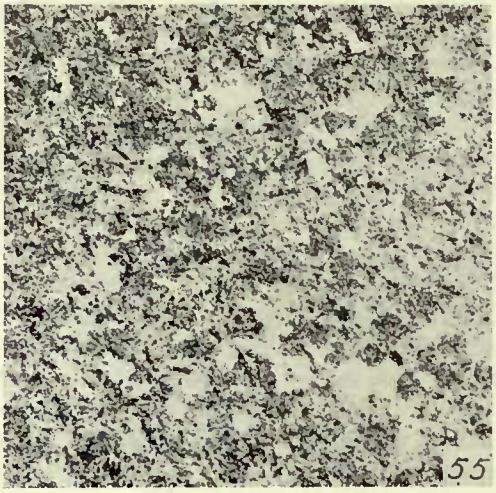


FIG. 22.

felsite It contains no obvious porphyritic crystals, but consists of a crypto-crystalline, felsitic ground-mass (that is to say, the crystalline elements cannot be separately distinguished), with small angular crystals of quartz evenly distributed throughout.

The larger clear spaces in Fig. 22 are holes in the thin slice of the rock, the others are the quartz grains.

Attrition Test No. 55.

Loss per cent.	Dry test	5·22
	Wet test	5·22
	Average	5·22

No. 10.

TRACHYTE OR KERATOPHYRE.

COED-Y-GLYN QUARRY, GLYN, RUABON, DENBIGHSHIRE.

A fine-grained green rock, which consists principally of orthoclase and plagioclase felspars in elongated narrow crystals, which show a markedly fluidal arrangement. Between them lie small grains of yellowish epidote and patches of chlorite. It is difficult to make certain whether this is a trachytic lava or an intrusive keratophyre. It contains no free quartz. A little calcite and decomposed iron oxides are the only other ingredients.

The elongated felspar crystals are clearly shown

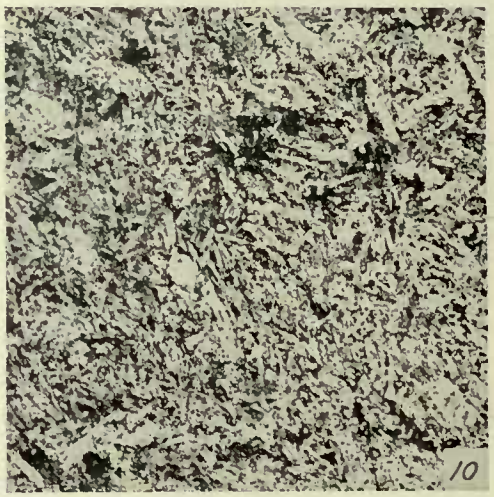


FIG. 23.

in Fig. 23; the dark matter is principally cloudy felspar; the epidote grains are too small to be distinguished.

Attrition Test No. 10.

Loss per cent.	Dry test	6 30
	Wet test	7·96
	Average	7·13

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BASALT AND DIABASE GROUP.

No group of rocks presents greater difficulties of nomenclature than this one. This is due to the subject having been attacked by different workers from diverse standpoints; for instance, the usage among German writers with regard to the terms "diabase" and "dolerite" is different from the English practice. But the practical surveyor need be in no way concerned with these difficulties, for his purpose diabase and dolerite may be regarded as synonymous terms.

In all the following stones, plagioclase is the normal type of felspar and augite the typical ferro-magnesian mineral. An important character in the dolerites and diabases is the "ophitic" structure, which is due to the early formation of the felspars and their subsequent inclusion in large irregular crystals of augite, &c. (See Fig. 29.) Olivine in large grains and crystals is a common mineral and iron ores are usually abundant.

The basalts are generally finer in texture than the dolerites. Epidiorites and uralitised diabases are rocks in which the original minerals have been altered with the production of new secondary minerals.

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BASALT AND DIABASE GROUP.

No. 1.

OLIVINE BASALT.

LINZ-ON-RHINE.

A fine-grained, very fresh, nearly black olivine basalt, which when examined with a lens shows many small green crystals of olivine and black specks of augite. Under the microscope the por-

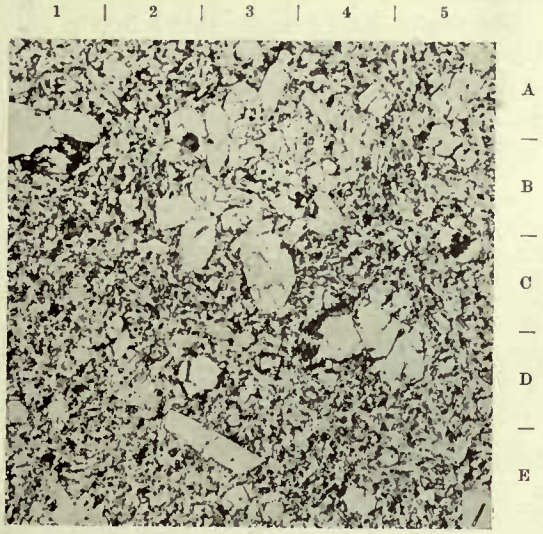


FIG. 24.

phyritic crystals of olivine are almost colourless, and show incipient weathering into serpentine along their cracks and borders; the porphyritic augites are idiomorphic and clear brown in colour, often zonal or with hour-glass structure, and usually aggregated together in glomero-porphyritic groups (B 3). The ground-mass consists of plagioclase felspar, finely granular augite, iron ores, and a little brown glassy material. The rock is free from steam cavities and contains no porphyritic felspar. (An analysis of this rock by Ebelmen is given by Zirkel, "Petrographie," Book II., page 900.)

Fig. 24 shows the fine ground-mass of small felspar laths, with augite granules and tiny crystals of iron oxide. A group of augite crystals lies in B 3, in E 2-3 is an isolated crystal. A-B 1 and C-D 4 contain clear crystals of olivine; they are cracked, and the dark material with them is serpentine.

Attrition Test No. 1.

Loss per cent.	Dry test	7·32
	Wet test	11·47
	Average	9·39

No. 90.

OLIVINE BASALT.

KINNEAR QUARRY, ST. FORT, FIFE.

A dark brownish-green rock, with small red spots, which are pseudomorphs in serpentine and hematite after olivine. The matrix in which these crystals lie consists of plagioclase felspar, granules of augite, and iron oxides. There is no clear fluxion structure or parallel arrangement of the components of the rock. Some of the larger olivines have had very perfect forms, but the augite is always in small irregular grains.

A large prism of olivine, with a pointed end, is seen in Fig. 25, E 4; the cracks in it are filled with

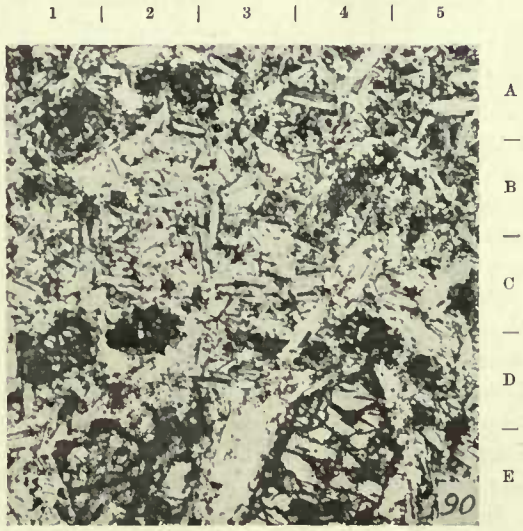


FIG. 25.
(Photographed in polarised light.)

iron oxides; all the black masses represent iron-stained olivine. The pale crystal in E 3 is felspar, and smaller, lath-shaped crystals occupy the greater part of the field. The little dark spots between the felspars are the augite grains.

Attrition Test No. 90.

Loss per cent.	Dry test	8·45
	Wet test	18·75
	Average	13·60

No. 6.

OLIVINE DOLERITE.

THE QUARRIES, WHITEHEAD, BELFAST, Co. ANTRIM.

An almost black stone with rather crystalline appearance where broken; small green crystals of

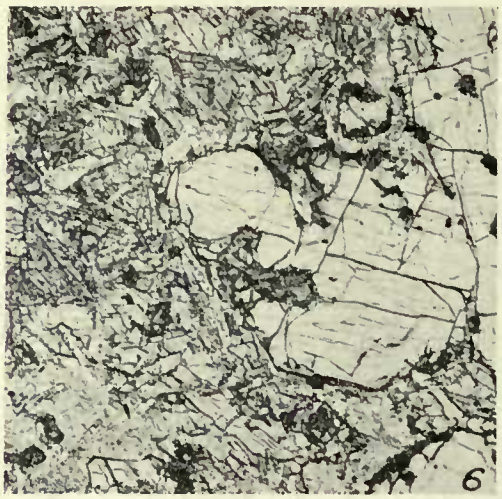


FIG. 26.

olivine and black spots of augite can be distinguished with the aid of a lens. It is an olivine dolerite (locally called "Basalt"), fairly coarse, with the olivine in groups of rounded grains, which in some cases have good crystalline outlines. The brownish augite is often in large plates, penetrated by many lath-shaped felspars. The rock is thoroughly ophitic in structure, and contains a considerable amount of felspar. Analcite and other zeolites are present in cloudy patches between the other constituents, and there are many specks and irregular masses of ilmenite. Most of the minerals show signs of decomposition, though this is in no case very advanced.

Several large crystals of olivine are shown in the right-hand side of Fig. 26. Augite occupies much of the remainder of the field; the lath-shaped felspars are seen lying in it.

Attrition Test No. 6.

Loss per cent.	Dry test	10·69
	Wet test	24·85
	Average	17·77

Nos. 52 and 53.

OPHITIC OLIVINE DOLERITE.

NEWBIGGING QUARRY, NEAR CERES, FIFE.

This is rich in olivine, which forms rounded crystals of various sizes, weathering on their surfaces to dark green serpentine. Elongated rectangular sections of plagioclase felspar are embedded in large irregular masses of brownish augite in typical ophitic fashion. Ilmenite and apatite are present also, and the rock is a good example of the class to which it belongs, both with regard to its structure and the character of its component minerals.

The augite is very clearly shown in Fig. 27, B-C 1-2 and C-D 5, and in smaller pieces in other parts of the figure. The large white masses, A 5, E 1, &c., are olivine. The felspar crystals are well exhibited in A 1, as they lie in the augite.

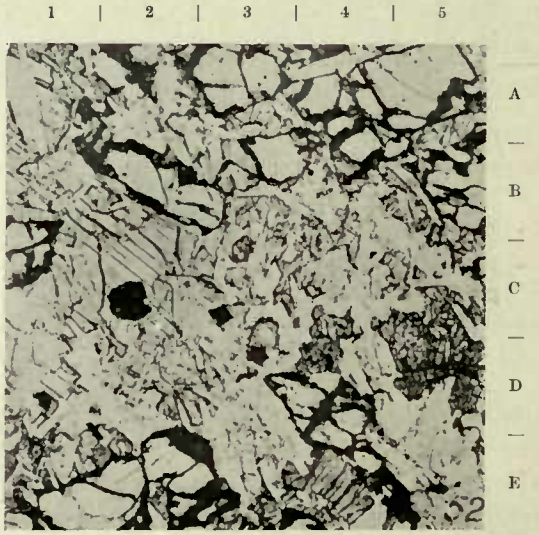


FIG. 27.

Attrition Test No. 52.

Loss per cent.	Dry test	10·05
	Wet test	19·63
	Average	14·84

Nos. 48 and 49.

OPHITIC OLIVINE DOLERITE.

BLAIR-ADAM, FIFE.

A rather coarse-grained ophitic olivine dolerite, overlying the lower coal measures, and, in common with Nos. 50 to 55, known locally as "Whinstone."

Large irregular plates of brownish augite enclose many small rectangular sections of plagioclase felspar. Olivine is abundant in rounded grains, often clustered together, and weathering on their edges to serpentine. Ilmenite and apatite are the accessories. The constituent minerals are on the whole fresh and in good condition, and the ophitic structure is of very typical character.

Attrition Test No. 48.

Loss per cent.	Dry test	8·88
	Wet test	14·45
	Average	11·66

No. 93.

OPHITIC DOLERITE.

Craigrothie Quarry, Cupar, Fife.

This is a dark greenish stone, with a distinctly coarser texture than the two preceding. It contains much plagioclase felspar in large crystals, which yield sharply rectangular sections and a small amount of pale brown interstitial augite. There are also plates of ilmenite and decomposition products, such as chlorite and calcite. In one or two



Fig. 28.

parts of the slide micropegmatite occurs between the felspars, but it is far from abundant.

Large felspar crystals fill most of Fig. 28. The black masses are mostly ilmenite. A little augite is seen in A 2.

Attrition Test No. 93.

Loss per cent.	Dry test	11·03
	Wet test	42·09
	Average	26·56

No. 129.

OPHITIC OLIVINE DOLERITE.

Freehall Quarry, Castlerock, Co. Londonderry.

In the hand specimen a compact greenish, finely crystalline stone. A coarse ophitic olivine dolerite, with crystals of olivine and large ophitic plates of

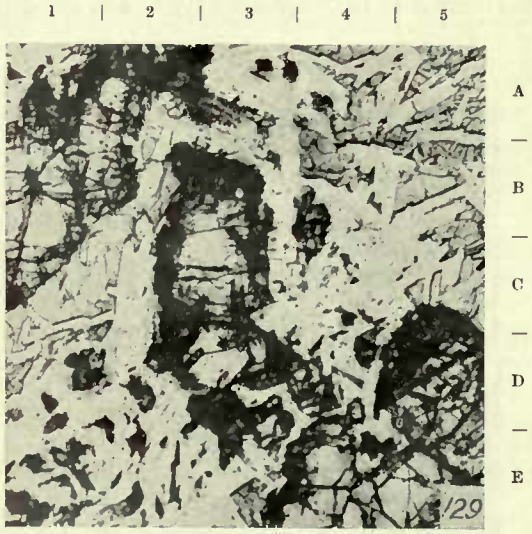


Fig. 29.

augite enclosing plagioclase felspar. All the minerals are, generally speaking, in good preservation, but the rock contains a quantity of chlorite and serpentine, resulting from the weathering of some of the olivine and augite. Its structure is highly characteristic of the group to which it belongs.

In Fig. 29 at A 4-5 and C 1 the augite is shown enclosing the felspar laths in typically ophitic manner. The large crystals of olivine, with their dark borders, are readily distinguished. The clear white parts are felspar.

Attrition Test No. 129.

Loss per cent.	Dry test	9·37
	Wet test	26·90
	Average	18·14

No. 3.

OLIVINE DIABASE.

TITTERSTONE QUARRIES, CLEE HILL, LUDLOW, SHROPSHIRE.

A rather coarse-grained olivine diabase, commonly known as "Clee Hill Basalt." In the hand specimen the green olivine, black augite, and dark grey plagioclase felspar, can easily be made out with the help of a lens. Under the microscope the olivine appears as clusters of rounded grains weathering to serpentine. The augite is greyish-brown and, though sometimes forming groups of idiomorphic crystals, is for the most part in small grains of irregular form, moulded on the felspars, so that the structure is of the "ophitic" type. The plagioclase

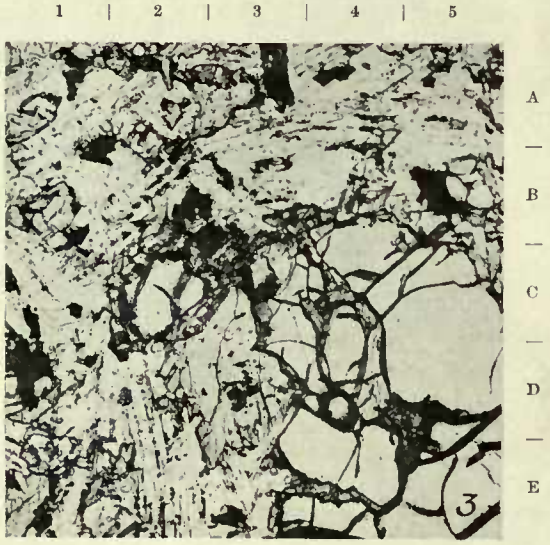


FIG. 30.

felspar occurs in long lath-shaped crystals. Ilmenite is abundant in irregular plates, and there are many fine needles of apatite. As a rule, all the ingredients are very fresh and well preserved for rocks of this kind, though there are small patches of cloudy analcite and other zeolites filling angular spaces between the felspars.

The most prominent feature in Fig. 30 is the olivine in the lower right-hand corner. In D 2-3, E 1, A 1 and B 1 augite is shown; the remaining clear portions are the lath-shaped felspars.

Attrition Test No. 3.

Loss per cent.	Dry test	6·00
	Wet test	8·45
	Average	7·22

No. 8.

OLIVINE DOLERITE.

CLEE HILL DHU QUARRIES, CLEE HILL, LUDLOW, SHROPSHIRE.

A dark, rather coarsely crystalline olivine diabase or dolerite, also known as "Clee Hill Basalt," in which the green olivine, black augite, and grey crystals of plagioclase, are clearly visible in the hand specimen. In all characters it closely resembles No. 3. The olivines are in clustered grains, and are weathering to serpentine along their cracks and borders. The augite is clear pale brown, and, though sometimes idiomorphic, is mostly moulded on plagioclase felspar. The structure of the rock is clearly ophitic. The elongated plagioclase felspars are fresh, and between them lies a small amount of a turbid material which is nearly isotropic, and is probably analcite. The ilmenite and apatite are the accessories, with here and there a few scales of biotite. The photomicrograph resembles Fig. 30.

Attrition Test No. 8.

Loss per cent.	Dry test	6·05
	Wet test	10·15
	Average	8·10

No. 57.

QUARTZ-ENSTATITE DIABASE.

DARBISHIRES' QUARRIES, PENMAENMAWR.

A compact grey stone, breaking with a clean cuboidal fracture. This variety of the Penmaenmawr enstatite diabase is fine grained, and consists mostly of small crystals of quartz and felspar. The quartz is clear and transparent; the felspars are cloudy and dull through weathering. Pseudomorphs of bastite after enstatite or bronzite occur in plenty, and have well-marked crystalline form. There is also some granular brownish augite, ilmenite weathering to leucoxene, and apatite. Even in the hand specimen the porphyritic structure is distinct, and is due to the presence of large phenocrysts of felspar and of enstatite.

The photomicrograph resembles Figs. 31 and 32, but shows a finer grain.

Attrition Test No. 57.

Loss per cent.	Dry test	3·91
	Wet test	7·03
	Average	5·47

Nos. 71 and 72.

QUARTZ-ENSTATITE DIABASE.

BRUNDRIT'S QUARRIES, PENMAENMAWR.

Consists of the same minerals as No. 57, but is coarser grained, all the ingredients occurring in

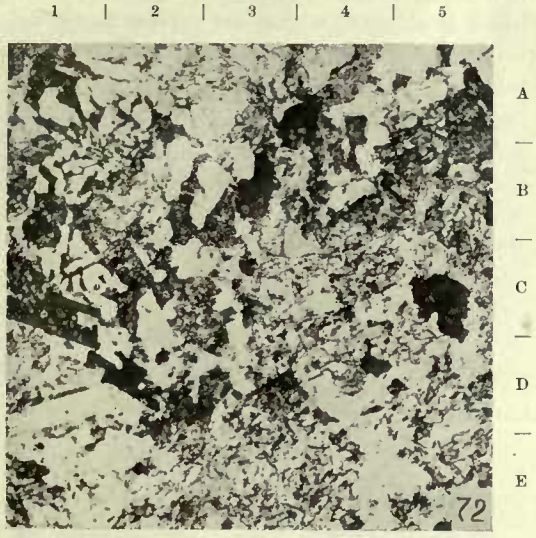


FIG. 31.

larger crystals. Well formed enstatites, weathering to bastite, and irregular grains of augite lie in a matrix of quartz and felspar. There is also a little biotite, apatite and ilmenite (weathering to leucoxene).

An acid segregation vein, rich in micropegmatite, is seen at one side of the section; it is shown in the upper left corner of the figure, where the clear parts are quartz, the grey parts are felspar, Fig. 31. In the opposite corner of the figure the grey portion represents enstatite, and the white part felspar (D 1). The black masses are ilmenite.

Attrition Test No. 72.

Loss per cent.	Dry test	2·98
	Wet test	5·17
	Average	4·07

No. 7.

ENSTATITE PORPHYRITE.

DARBISHIRES' QUARRIES, PENMAENMAWR, CARNARVONSHIRE.

In the hand specimen this stone is very like Nos. 57 and 72. The Penmaenmawr rock is well known, and has been frequently described. Mr. Harker, ("Petrology," Ed. 3, p. 136) regards it as a quartz-bronzite diabase. Dr. Teall has described and figured it ("British Petrography," Pl. 35, Fig. 2) as an enstatite diorite. There can be no doubt that it varies a good deal in structure, though it seems always to contain the same assortment of minerals. It was also described by Mr. J. A. Phillips, and by Mr. Waller, who gives chemical analyses of the predominant type of the rock, and also of the acid veins which intersect the main mass. Quite recently a German petrographer has described it as a "quartz norite."

This sample is a fine-grained grey rock, which consists principally of plagioclase felspar, micropegmatite, and bastite after enstatite. It contains also a little augite and iron ores. The rock shows a distinct porphyritic structure, as the enstatites are larger than the other ingredients; and there are also some idiomorphic porphyritic felspars. This is consequently the "andesitic" variety mentioned by Mr. Harker, and is perhaps best described as an enstatite porphyrite.

Attrition Test No. 7.

Loss per cent.	Dry test	2·44
	Wet test	3·76
	Average	3·10

No. 88.

ENSTATITE DIABASE.

DARBISHIRES' QUARRIES, PENMAENMAWR.

An even-grained green and white speckled stone;

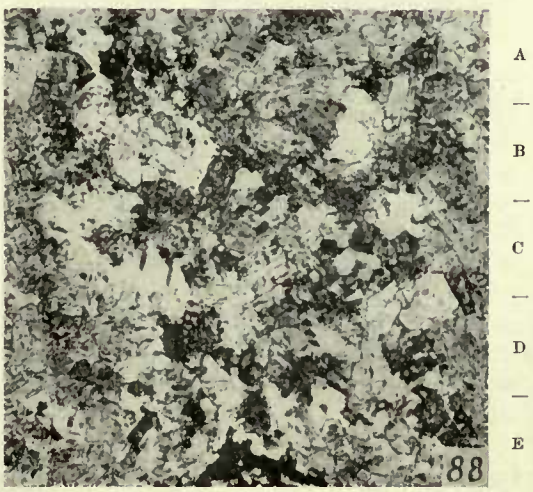


FIG. 32.

it is one of the coarser types of Penmaenmawr rock. The slide, Fig. 32, shows idiomorphic enstatite,

brownish augite, with basal lamellation, felspar and quartz. There is a considerable amount of micropegmatite in this specimen. Iron ores and apatite are also present. The iron oxides are weathering to leucoxene, and the felspars are turbid with decomposition.

Except the piece in E 3, all the darker material shown in the figure is turbid felspar. Much of the paler matter is enstatite A-B 4-5, B 2, C-D 5. Quartz in irregular-shaped clear patches occurs in C 4 and B-C 4-5.

Attrition Test No. 88.

Loss per cent.	Dry test	2·54
	Wet test	2·78
	Average	2·66

Nos. 86 and 87.

PORPHYRITIC DIABASE.

WESTCOTT QUARRY, BRIDFORD, SOUTH DEVON.

(Nine miles south-west of Exeter.)

A dark green porphyritic diabase, with large greenish felspars disseminated through a fine ground-mass. The phenocrysts of felspar are apparently labradorite, decomposed, and infiltrated with chlorite. The remainder of the rock consists



FIG. 33.

of smaller felspar, pale brown augite, and chlorite after augite, iron oxides, apatite, and a little quartz. The structure is ophitic, as the felspars have mostly good crystalline outlines, while the augite is moulded upon their surfaces.

In Fig. 33 the relatively large size of the porphyritic felspar is not evident; portions of crystals are seen in A 2 and C-E 4-5, but frequently a single crystal would more than fill the whole field of the photograph. The black patches across the centre of the figure represent areas of opaque white kaolinised felspar. The smooth grey mineral in D-E 3 is chlorite, which has replaced original augite; a few grains of unaltered augite are visible in A 1.

Attrition Test No. 86.

Loss per cent.	Dry test	9·28
	Wet test	14·55
	Average	11·91

No. 12.

DIABASE.

ROSTREVOR, CO. DOWN.

This is a rather coarse-grained crystalline green stone with white specks. "At Rostrevor, Co. Down,

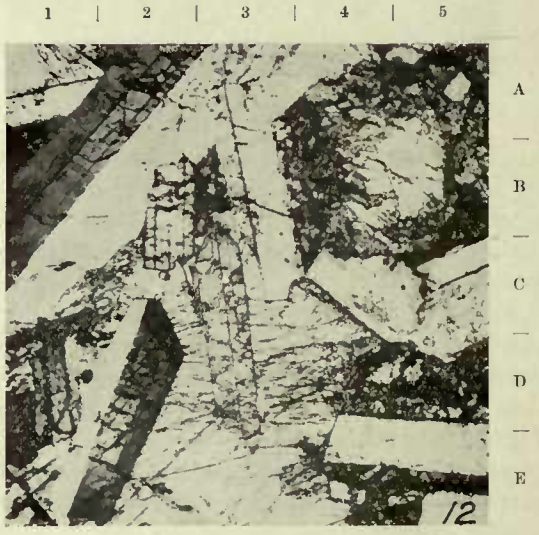


FIG. 34.

(Photographed in polarised light.)

on the north side of Carlingford Lough, occurs a uralitic diabase (proterobase). It contains, according to Prof. von Lassaulx, plagioclase, augite, uralite, chlorite, magnetite, and apatite. The felspar gives lath-shaped sections. The augite varies from reddish-brown to colourless. It is altered at the margins into green fibrous uralite. The twin planes of the augite can be followed into the uralitic aggregates. . . . The chlorite is distinguished from the hornblende, which it resembles in colour, by its feeble double refraction. The rock is termed a

'eucrite' by Prof. von. Lassaulx. . . . The ophitic structure is most pronounced, and the iron ore occurs in the large ragged plates so characteristic of the older diabases." — J. J. H. Teall, "British Petrography," p. 248.

This rock agrees so closely with Dr. Teall's description that there can be no doubt it has come from the same source. It is a diabase of coarse-grained type.

The large plagioclase crystals appear in the photomicrograph, Fig. 34, to occupy most of the area. Being viewed by polarised light, several of them have one part dark, while the other is light; this is the effect of the twining in the crystal. In the lower part of the figure E-D 2-4 is a large mass of augite; in D 2 it is seen wrapping round the end of the felspar crystals in the typical ophitic manner. In B 5 the clear mass of augite is seen surrounded by a dark rim of uralite. The black pieces in D 1 and D 5 are iron oxides.

Attrition Test No. 12.

Loss per cent.	Dry test	10·06
	Wet test	13·67
	Average	11·86

No. 120.

DIABASE.

Falcarragh Quarry, Co. Donegal.

This is similar in appearance to No. 12, but is rather darker. A decomposed, fairly coarse-grained diabase. The rock contains brown augite, which often shows a basal lamellation and approaches diallage; much idiomorphic plagioclase felspar, which is weathering to muscovite, epidote, &c.; and a considerable amount of dark green hornblende, often implanted on the surface of the augite. Part of this last mineral is primary and part secondary, as it can be seen to replace the pyroxene in fibrous pale green aggregates. Iron oxides and quartz are both present; also small columnar prisms of apatite. This rock might also be regarded as a *quartz-augite diorite* of somewhat unusual character.

The clear portion of Fig. 35, A 3-5 is all part of one large felspar crystal; the black patches within this area are kaolinised. The grey streaky mineral, A-B 2 and D-E 3-4, is augite; D 2 is the same. The black mass B 4-5 is iron oxide, and so is A-B 1, C-D 3; but in C 5 and D 1 the black mass of the figure represents kaolinised felspar.

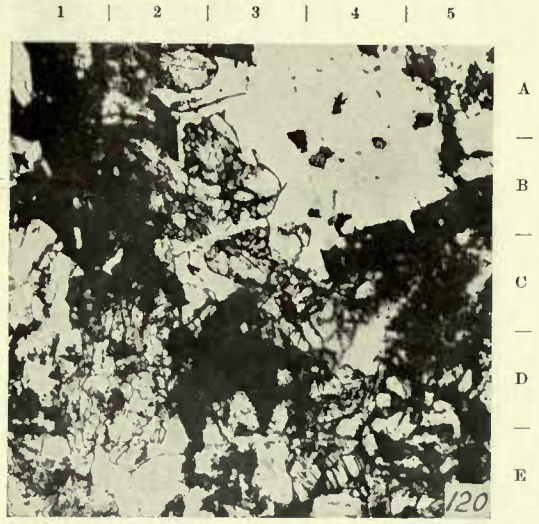


Fig. 35.

Attrition Test No. 120.

Loss per cent.	Dry test	7·13
	Wet test	8·30
	Average	7·71

No. 56.

OPHITIC DIABASE.

Trusham Quarry, South Devon.

This stone is dark green in colour, with abundant spots of paler green and shining cleavage faces of felspar. The most abundant ingredient of the rock is plagioclase felspar in large rectangular crystals, which are filled with chlorite, epidote, and other secondary minerals. Augite has originally formed irregular plates, enveloping the felspar, but has almost entirely weathered to chlorite; undecomposed areas of augite are also to be seen. Another mineral in the section is ilmenite in black opaque patches, which are passing into granular leucoxene. Quartz and calcite are also present, and are both probably secondary.

The grey masses in Fig. 36, A 5, E 4, are fresh augite crystals; some of the clear spaces, D 5, C 4, &c., are augite altered to chlorite, the clear areas in B 1 are quartz crystals. Rectangular felspars are seen in many parts of the photo, D 3-4, A 1-3,

C 4. The black spots represent ilmenite and leucoxene.

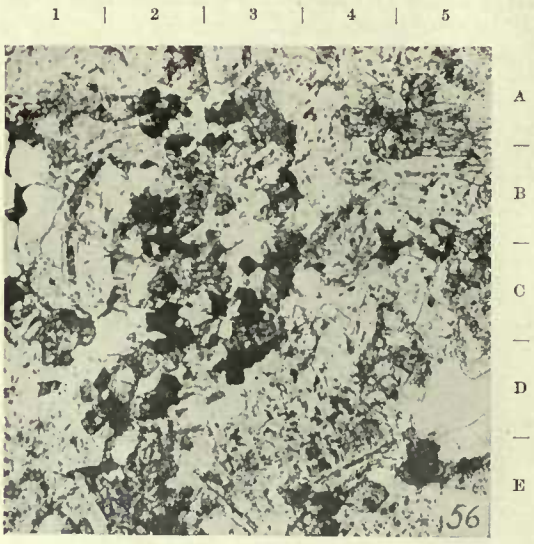


FIG. 36.

Attrition Test No. 56.

Loss per cent.	Dry test	10·64
	Wet test	17·28
	Average	13·96

Nos. 101 and 102.

OPHITIC DIABASE.

MOEL-Y-GEST QUARRIES, CARNARVON.

Large plates of pale brown augite of very irregular shape enclose many small rectangular sections of felspar. Skeleton growths of ilmenite, weathering to leucoxene, are also visible. The bulk of the rock is made up of plagioclase crystals, turbid with decomposition, and pale green chlorite after augite. The photomicrograph resembles Fig. 36.

The hand specimen is rather a pale grey stone, with small indefinite white patches and a uniform granular appearance.

Attrition Test No. 102.

Loss per cent.	Dry test	5·76
	Wet test	8·79
	Average	7·27

Nos. 75 and 76.

DIABASE.

CENTRAL WALES GRANITE COMPANY'S QUARRIES, LLANDRINDOD, RADNORSHIRE.

This is a fine-grained grey stone, with a dull fracture, and greenish tinge on weathered surface. A diabase, with large rectangular sections of plagioclase felspar, enveloped in chlorite, the result of the alteration of ophitic augite. Olivine is also represented by pseudomorphs of calcite. Leucoxene, calcite, chlorite, and other secondary minerals, are everywhere abundant; all the ferro-magnesian minerals have decayed, and there is reason for believing that enstatite may have been originally present.

The dark masses in Fig. 37 are leucoxene;

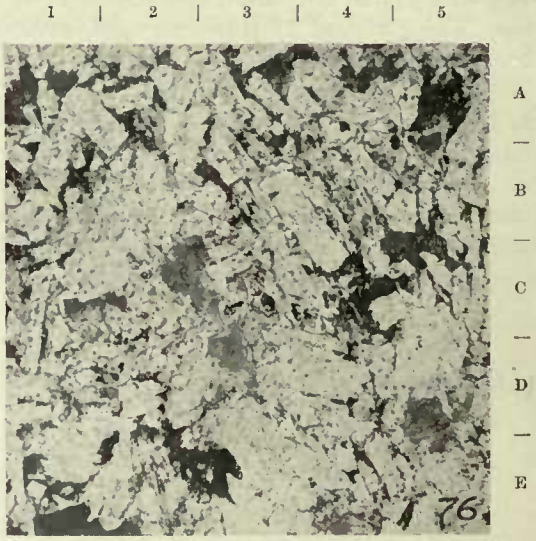


FIG. 37.

chlorite is seen, as indefinite grey material, in C 2 and D 5; most of the remainder is felspar.

Attrition Test No. 76.

Loss per cent.	Dry test	9·37
	Wet test	16·94
	Average	13·15

No. 127.

DIABASE.

HILL TOP QUARRY, NEAR DUNSFORD, SOUTH DEVON.

A much-decomposed diabase, showing remains of felspar, augite, &c., converted into chlorite, kaolin, calcite, and other secondary products. The original rock was porphyritic, but the larger crystals have been entirely altered. Some of the felspars of the ground-mass can still be detected. The rock contains also dark crystals of iron oxide. The stone is fine grained and almost black.

The only constituent minerals to be distinguished in the figure are the large altered porphyritic felspar crystals, Fig. 38, C 1 and C 4; the smaller

white and grey bodies are also felspar; the black spots are iron oxides.

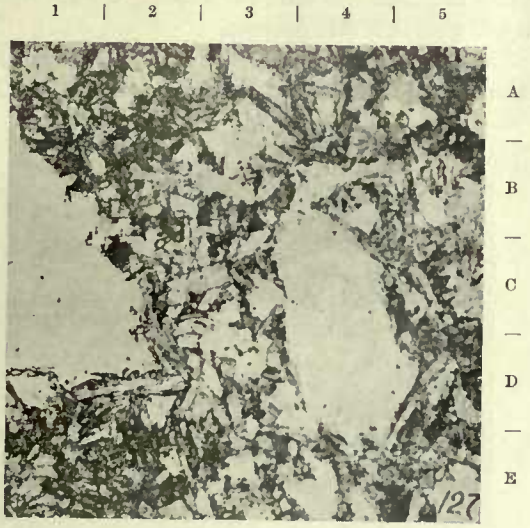


FIG. 38.

Attrition Test No. 127.

Loss per cent.	Dry test	5·13
	Wet test	6·69
	Average	5·91

No. 130.

DIABASE.

GREAT HILL QUARRY, NEAR EXETER.

A similar rock to the last, but not so thoroughly decomposed. Much of the original felspar remains, and the augite has partly changed to uralite. In

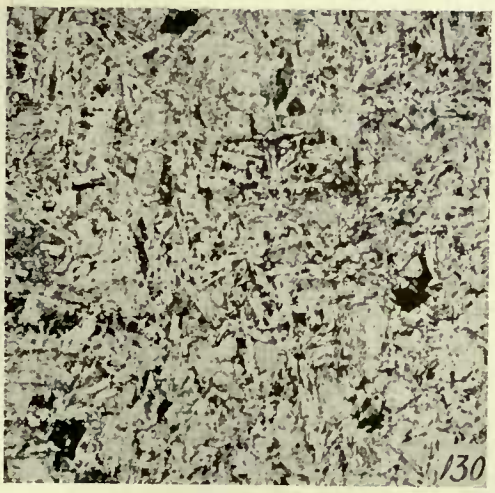


FIG. 39.

this rock, also, the structure is porphyritic, though not in so marked a degree as in the previous case.

It is not possible to distinguish the uralitic material clearly in Fig. 39, but the lath-shaped felspars are evident, and the former mineral lies between them. The black spots are iron oxides. The porphyritic character is not shown in the figure.

Attrition Test No. 130.

Loss per cent.	Dry test	2·44
	Wet test	4·39
	Average	3·42

Nos. 44 and 45.

URALITIC DIABASE.

MEENAWEARY QUARRY, BUNCRANA, CO. DONEGAL.

A dark-coloured, rather coarse-grained massive uralitic diabase. There is little schistosity, and the

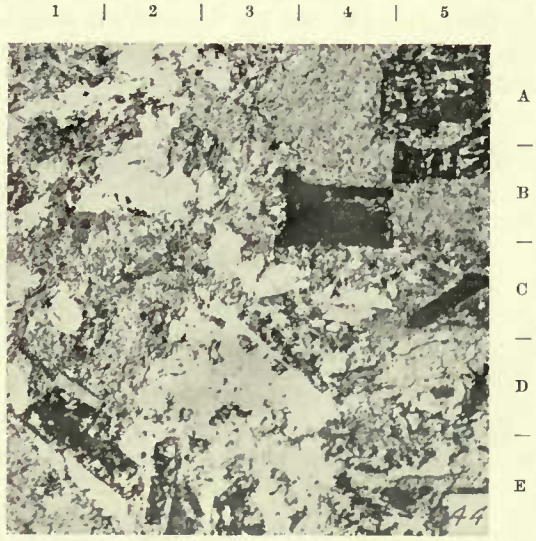


FIG. 40.

rock can hardly be grouped with the epidiorites, as the original ophitic structure can still be clearly seen, though the primary pyroxene has been entirely replaced by secondary fibrous green amphibole (uralite). This forms nests, patches, and irregular masses, though the outlines of pyroxene can usually be detected. The felspars are being replaced by kaolin, muscovite, and epidote. There is a little quartz, part of which may be primary. Large plates and networks of ilmenite are also conspicuous. The amount of shearing which the rock has undergone seems to be comparatively small. Large apatites are frequent, and usually unbroken; the rock contains, also, a small amount of biotite.

The hand specimen is similar to No. 120, but is rather darker.

The most prominent feature in the figure is the ilmenite in the upper right corner, Fig. 40. The grey portions, A 4, B 5, &c., are masses of uralite; decomposed felspars are seen in E 1-2; secondary fresh felspar and some quartz occupy the clear spaces in the centre of the figure.

Attrition Test No. 44.

Loss per cent.	Dry test	3·51
	Wet test	5·91
	Average	4·71

No. 47.

EPIDIORITE.

FINCAIRN QUARRY, NEAR LONDONDERRY.

A rock very similar to the last, and consisting of the same minerals. See Fig. 41, which it resembles, but has a finer grain and a somewhat schistose structure under the microscope.

Attrition Test No. 47.

Loss per cent.	Dry test	12·50
	Wet test	26·61
	Average	19·55

No. 46.

EPIDIORITE.

ARDLOUGH QUARRY, NEAR LONDONDERRY.

Pale green epidiorite, consisting of actinolitic hornblende in fibres and irregular clusters, with chlorite, epidote, and plagioclase felspar. The last is much broken and granulitised by the stresses to which the rock has been subjected. A small quantity of quartz is also present.

The paler parts of Fig. 41 represent felspar and chlorite; a mass of kaolinised felspar lies in D 2.



FIG. 41.

In C 1 and D 1 there is a mass of actinolite and chlorite; the granular bodies in A, B, C, 3, 4, 5, are epidote crystals.

Attrition Test No. 46.

Loss per cent.	Dry test	18·80
	Wet test	41·06
	Average	29·93

ANDESITES.

Chemically this group of lavas is intermediate between the more siliceous granites and porphyries and the less siliceous dolerites and basalts; the andesites are very similar to the porphyrites. The texture is commonly fine-grained; a felted ground-mass of small lath-shaped felspars is typical (see Figs. 42, 44), while phenocrysts of felspar, augite, and hornblende, may or may not be present.

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ANDESITES.

Nos. 50 and 51.

ANDESITE.

FOODIE QUARRY, CUPAR, FIFE.

A fine-grained, dull, dark-coloured stone, with a slight greenish tinge. There are in this rock porphyritic crystals of plagioclase felspar (the clear mass with transverse cracks to the left of Fig. 42) scattered through a crystalline matrix, consisting of small lath-shaped plagioclase and granular brownish-green augite. A little apatite, iron ores, and biotite, are also present, together with chlorite, limonite, and other secondary products. Fluxion structure is well shown in the parallel arrangement of the felspars of the ground-mass.

Most of the dark specks in the figure are augite crystals, a few of them are iron ores.

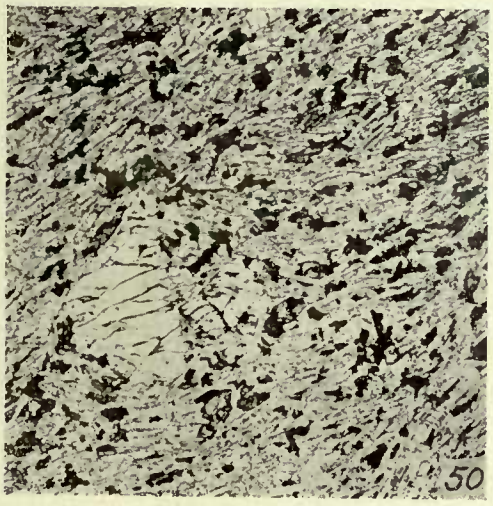


FIG. 42.

Attrition Test No. 50.

Loss per cent.	Dry test	9·58
	Wet test	21·78
	Average	15·68

No. 91.

ANDESITE.

DUNNIMONKSHILL QUARRY, STRATHMIGLO, FIFE.

A banded, fluidal, dark brown andesite, which consists entirely of small lath-shaped crystals of felspar, arranged with their long axes more or less parallel. There is no augite or other ferro-magnesian mineral, but much magnetite and hematite in small grains and irregular stains, and these give the rock its dark-red tint. The felspar is

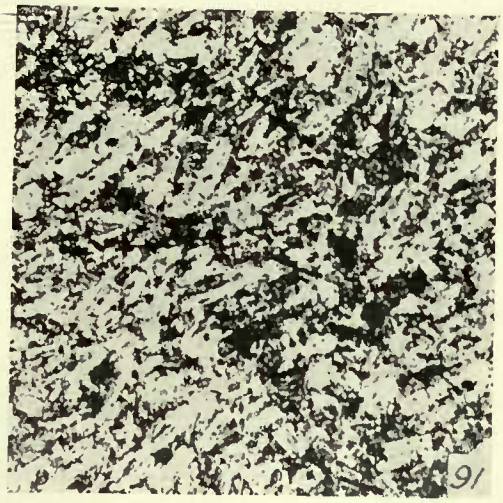


FIG. 43.

(Photographed in polarised light.)

mostly plagioclase, but there seems to be a fair proportion of orthoclase mingled with this. Fig. 43.

Attrition Test No. 91.

Loss per cent.	Dry test	5·76
	Wet test	10·30
	Average	8·03

No. 92.

BIOTITE ANDESITE.

CRAIGOWERHOUSE QUARRY, AUCHTERMUCHTY, FIFE.

A fine-grained felspathic stone, weathering green along the joints. This is a porphyritic and fluidal andesite, with small phenocrysts of plagioclase felspar in a matrix of long, narrow plagioclase crystals, which are all in winding streams, showing a perfect fluxion structure. Iron oxides, apatite, and limonite, are also present, but the ferro-magnesians are all decomposed. There is reason to believe, however, that at one time the rock contained porphyritic biotite in idiomorphic crystals, which were corroded and surrounded by borders of opaque black magnetite. If so, they are no longer identi-

fiable. The general character of the rock agrees with the supposition that it is a biotite andesite.

In the photomicrograph, Fig. 44, two of the phenocrysts of plagioclase are present as clear white

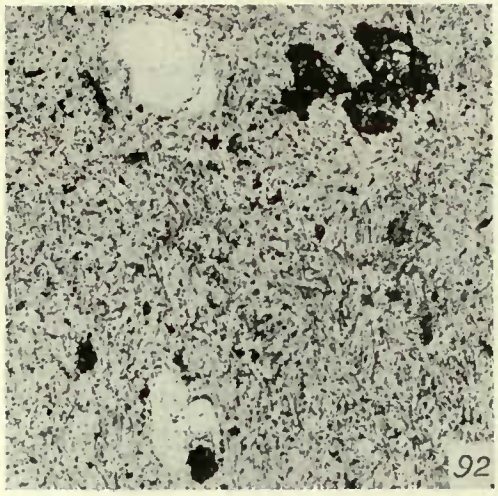


Fig. 44.

bodies. The dark masses are the iron-stained, altered ferro-magnesian minerals.

Attrition Test No. 92.

Loss per cent.	Dry test	5·37
	Wet test	6·59
	Average	5·98

No. 54.

ANDESITE.

Mount Quarry, Cupar, Fife.

A dark grey porphyritic andesite, with large crystals of plagioclase felspar in a fluidal, crystalline, felspathic ground-mass. The large felspars have well-defined crystalline form and contain but few enclosures. Black iron oxides and small grains of augite, chlorite, and calcite, occur in the ground-mass; but plagioclase felspar forms by far the greater part of the rock.

The figure shows a group of large porphyritic

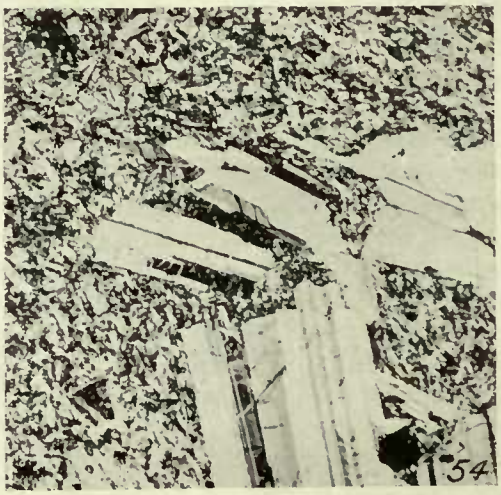


Fig. 45.

(*Photographed in polarised light.*)

plagioclase crystals lying in ground-mass of the smaller crystals, Fig. 45.

Attrition Test No. 54.

Loss per cent.	Dry test	8·44
	Wet test	12·99
	Average	10·71

HORNFELS.

In this group are placed rocks which have been altered by contact with masses of heated igneous rock. In most of these the minerals are fresh and the texture is fine grained. Either an argillaceous or an igneous rock may pass into the hornfelsed condition.

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HORNFELS.

No. 118.

CORDIERITE-BIOTITE HORNFELS.

SHIELS, BELHELVIE, ABERDEEN.

A dark grey stone, with a crystalline, granular appearance on the freshly-fractured surface; it has

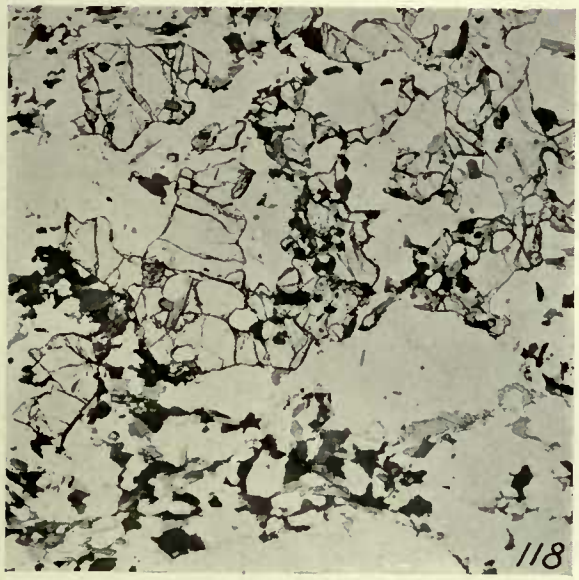


FIG. 46.

a slightly pink tinge in places. This is an excellent example of the rocks of this group, as the contact structures are well developed and the minerals are very fresh. Though cordierite is abundant, it might easily be overlooked, as it is as clear as quartz and does not often show the characteristic pleochroic halos round small enclosures. Quartz, orthoclase, and plagioclase, are also abundant, and there is a considerable amount of a dark reddish-brown biotite, such as is usually found in contact-altered rocks. Large spongy crystals of pale pink garnet, small needles of sillimanite, and grains of iron oxide, are the other ingredients. The rock has in places a somewhat schistose structure.

The photomicrograph, Fig. 46, shows clearly enough the large crystals of garnet, with their sharp black outlines, and the dark flakes of biotite; the clear portions of the figure contain the grains of quartz, orthoclase, and plagioclase felspar, and the cordierite; but these minerals are not distinguishable in the photo, because they are so fresh. Viewed with crossed nicols, the texture of the stone appears much finer.

Attrition Test No. 118.

Loss per cent.	Dry test	5·86
	Wet test	10·25
	Average	8·05

No. 42.

BIOTITE HORNFELS.

SHAP, WESTMORELAND.

More generally known as "Shap Blue Stone." This is a dark, fine-grained, dull, compact rock, which has evidently been affected by contact alteration. It consists mainly of small flakes of dark brown biotite (dark specks in the Fig. 47), and granules of quartz and felspar (the clear parts in the figure).

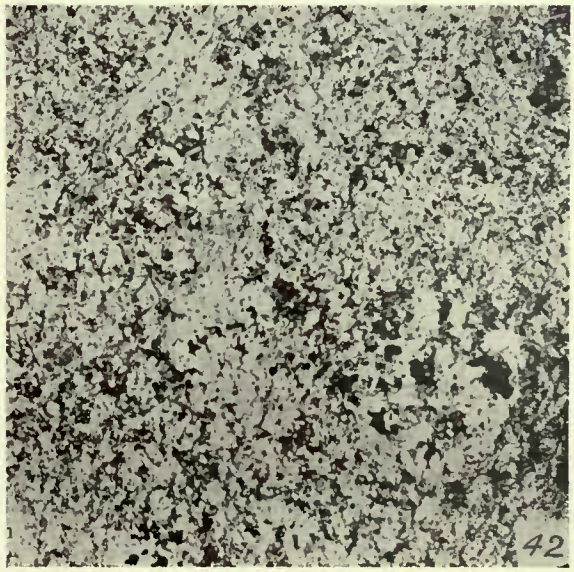


FIG. 47.

"SHAP BLUE STONE."

The rock is irregularly streaked, and has a spotted or knotted character. Small crystals of chlorite, pyrites, and iron oxide, are also seen in the section and in the figure as dark masses.

Attrition Test No. 42.

Loss per cent.	Dry test	6·88
	Wet test	8·98
	Average	7·93

No. 9.

HORNFELSED GREENSTONE ("ELVAN").

PENLEE QUARRIES, PENZANCE, CORNWALL.

Fine-grained, dark green stone, but coarser in texture than the other examples of the groups here

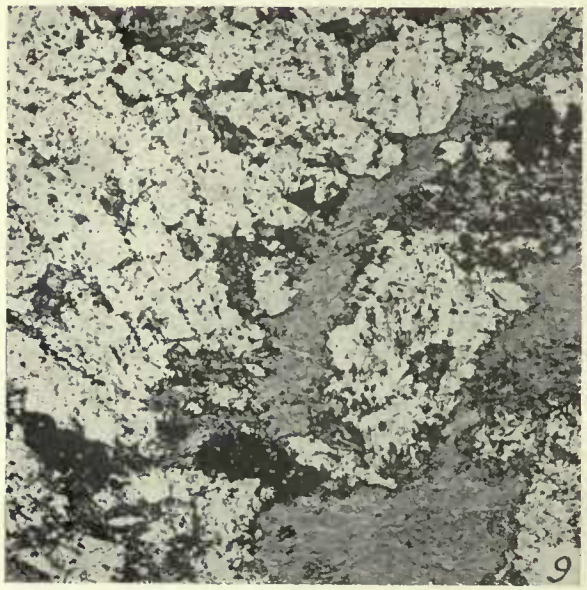


FIG. 48.

PENLEE ELVAN.

considered; it is a hornfelsed greenstone. This has been originally a diabase, which has subsequently been altered by the heat given off by an adjacent intrusive mass of granite. It consists of plagioclase felspar, in large crystals (Fig. 48, the paler part), some of which have been broken and crushed by earth movements, surrounded by masses of fibrous green hornblende (grey in the figure), mixed with a little brown biotite and indefinite patches of oxides of iron and granules of sphene. The black patches in the figure are the iron oxides.

Attrition Test No. 9.

Loss per cent.	Dry test	5·42
	Wet test	7·52
	Average	6·47

No. 128.

DIABASE HORNFELS.

MOONLAND QUARRY, MORETON HAMPSTEAD, SOUTH DEVON.

A fine-grained, very dark stone, with glistening specks on the fresh surface. This is an excellent example of a rather rare group of rocks. It is a diabase hornfels—*i.e.*, a diabase, like the other specimens from this locality, which has been completely recrystallised by the heat of the granite mass adjoining. In consequence, the minerals are entirely fresh, and the structure of the original rock, which was porphyritic, has been transformed to a mosaic of small, perfectly clear grains of felspar, Fig. 49, with similar grains of brownish-green hornblende (grey in the figure) lying between. In this mosaic lie larger patches of hornblende and spongy areas of black opaque iron oxides. A little

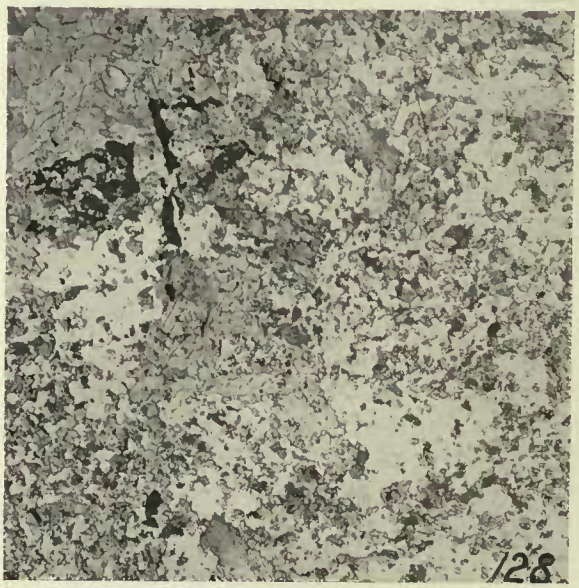


FIG. 49.

apatite and a few flakes of brown biotite are the only other minerals which call for remark.

Attrition Test No. 128.

Loss per cent.	Dry test	5·57
	Wet test	9·86
	Average	7·71

QUARTZITES AND SANDSTONES.

The stones in this group have all been formed from the *débris* of pre-existing rocks, their essential constituent is quartz sand; the purer varieties contain practically nothing else. In addition to quartz, the mineral felspar is present in many sandstones (see Nos. 58 and 113), and mica is often an important accessory (No. 78); sometimes calcareous organic remains (No. 38) or fragments of other rocks are included (Nos. 30 and 70).

The cementing material which holds the grains together may be quartz, iron oxide, or calcite, other minerals less frequently; sometimes it is argillaceous matter.

The principal difference between a quartzite and a sandstone is that in the former the cementation by interstitial quartz or by the secondary growth of the original quartz grains is more complete than in the latter; the percentage of SiO_2 in quartzite is usually higher than in sandstones.

The term "Greywacke" is applied to *impure* sandstones or grits of various kinds.

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QUARTZITES AND SANDSTONES.

No. 83.

QUARTZITE.

OPPREBAIS, BELGIUM.

A fine-grained, grey, compact, highly-siliceous stone, which consists almost entirely of grains of quartz; there is also a little felspar (much altered), with a little iron oxide, zircon, tourmaline, and other accessory minerals.

The fineness of the grains of quartz and their close interlocking one with another are shown in Fig. 50 (see the white grain B 2 and the dark grains E 2 and E 1). These are two important factors which influence the quality of the stone.

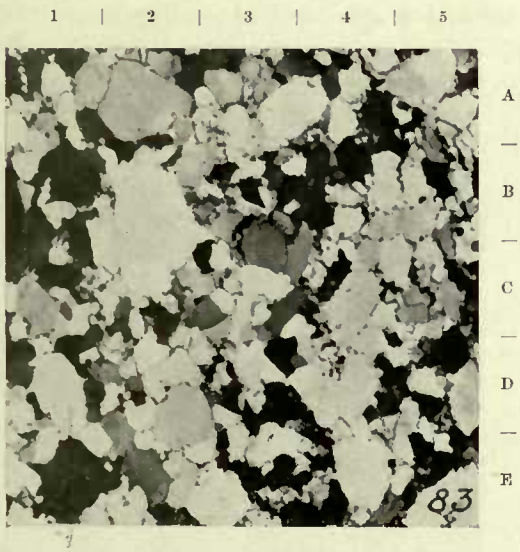


FIG. 50.

(Photographed in polarised light.)

Some grains appear black, some white or grey, according to the direction in which the light traverses them.

Attrition Test No. 83.

Loss per cent.	Dry test	3·42
	Wet test	4·05
	Average	3·73

No. 105.

FERRUGINOUS QUARTZITE.

WINFORD, NEAR BRISTOL, SOMERSETSHIRE.

The stone is known locally as "Fire" or "Iron" Stone. It is a hard, fine-grained, pink quartzite, with rusty staining on the joints. It is composed

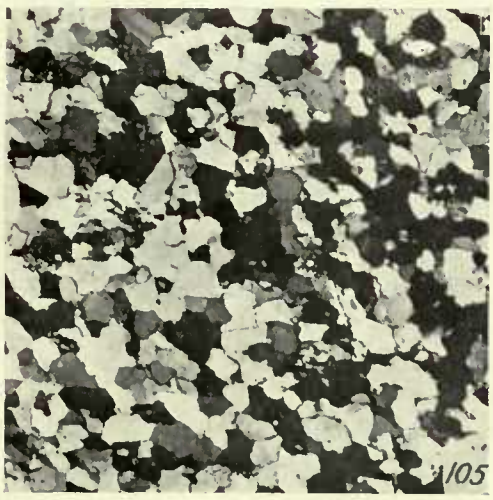


FIG. 51.

"FIRE" OR "IRON" STONE.

(Photographed in polarised light.)

almost completely of small, irregular, or slightly-rounded, closely-interlocking grains of quartz, with a little decomposed felspar. Practically all the grains shown in Fig. 51 are quartz. The microscope reveals a few minute crystals of zircon and rutile, white mica, and tourmaline, as well as iron oxide, weathering to leucoxene; but the total amount of these accessory ingredients is so small as to be negligible.

Attrition Test No. 105.

Loss per cent.	Dry test	3·81
	Wet test	4·98
	Average	4·39

No. 16.

QUARTZITE.

CHERBOURG.

A hard, compact grey stone, with slight yellow staining in the joints. Under the microscope the clastic or fragmental structure is well seen; the

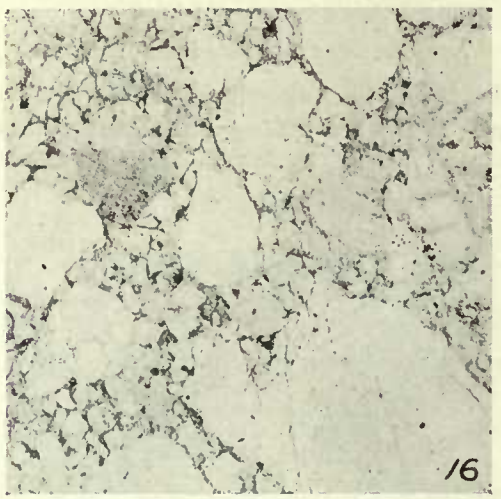


FIG. 52.

round quartz grains, which are often 1 mm. in diameter, lie in a matrix of much smaller, angular, and rounded pieces. All the grains are firmly cemented together by siliceous materials, containing a little mica and chlorite. There is almost no felspar in the rock; the accessory minerals are zircon and iron oxides, with a few specks of pyrites.

The quartz grains are mostly optically simple, and may have come from granitic rocks; a few are crushed, and may have been derived from gneisses or schists of the metamorphic group.

Fig. 52 is taken by ordinary light to show how these stones appear in thin slices without the polariscope; the two sizes of grain are clearly distinguishable.

Attrition Test No. 16.

Loss per cent.	Dry test	5·47
	Wet test	5·95
	Average	5·71

No. 96.

QUARTZITE.

CHERBOURG.

A pale yellowish-brown stone, hard, with a somewhat more shiny fracture surface than any of the other quartzites here described; the grains can easily be distinguished by the unaided eye. The microscope demonstrates that this stone differs from the preceding one, No. 16, from the same locality, in that the quartz grains are nearly all of the larger size; only here and there are the smaller grains present. The grains are mostly in close juxtaposition, while a siliceous cement fills up any remaining space.

Attrition Test No. 96.

Loss per cent.	Dry test	4·98
	Wet test	8·20
	Average	6·59

No. 11.

QUARTZITE.

HARTSHILL, NEAR ATHERSTONE, WARWICKSHIRE.

A grey or slightly-brown compact stone. It contains angular and sub-angular grains of quartz, along with fairly numerous pieces of weathered orthoclase felspar, and small fragments of what appears to be a kind of felsite—a fine-grained acid igneous rock, Fig. 53, C 2, C 3; these are visible to

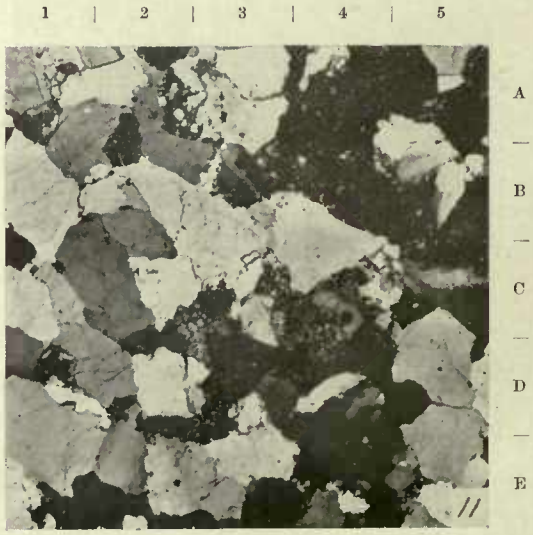


FIG. 53.

(Photographed in polarised light.)

the naked eye on a smooth surface of the stone as small pale or brown specks. Some of the quartz, A 2, A 3, exhibits signs of strain in polarised light, and has probably come from metamorphic rocks. The section shows, also, a little calcite, muscovite (mica), iron oxides, and zircon.

Attrition Test No. 11.

Loss per cent.	Dry test	6·25
	Wet test	8·35
	Average	7·30

No. 125.

GREYWACKE.

GLYNRHONWY SLATE QUARRY, SOUTH-WEST SIDE OF LLANBERIS LAKE, CARNARVONSHIRE.

This is a medium-grained, dark green greywacke or impure grit. The slide shows many grains of quartz, mostly sub-angular, ranging up to $\frac{1}{30}$ in. in diameter, embedded in a mass of fine quartz, weathered felspar, scaly mica, pale green chlorite, and iron oxides. The chlorite gives the rock its characteristic colour. Calcite is fairly abundant in small grains and irregular patches among the other ingredients.

Fig. 54 is from a photograph taken by ordinary light; all the white patches represent quartz grains; chlorite is seen as dark pieces in A 1 and A 3-4; close to the last-mentioned bit of chlorite is a flake

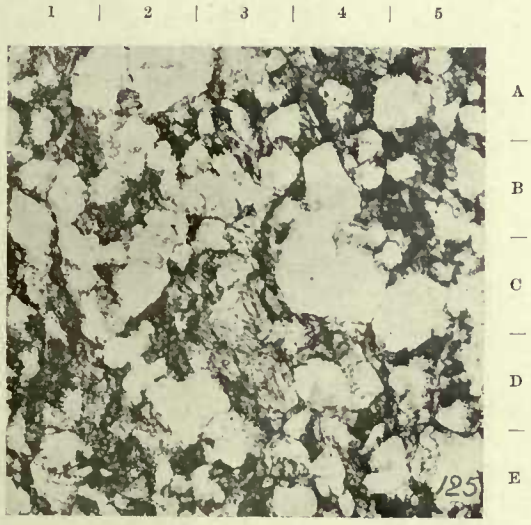


FIG. 54.

of mica, appearing as a white rod. Most of the black spots in A 5 and B 5 are iron oxides. The streaky material in D 3 is calcite.

Attrition Test No. 125.

Loss per cent.	Dry test	10·06
	Wet test	19·82
	Average	14·94

No. 126.

GREYWACKE.

GLYNRHONWY SLATE QUARRY, SOUTH-WEST SIDE OF LLANBERIS LAKE, CARNARVONSHIRE.

A similar rock to the last, but coarser, the pebbles being sometimes $\frac{1}{8}$ in. to $\frac{1}{4}$ in. in diameter.



FIG. 55.

Most of them are quartz, with many liquid enclosures; a few are much-weathered felspar. The matrix is like that of the previous rock, but its elements are larger, as a rule, though in some places it resembles a fine shale with very small grains of quartz, flakes of mica, and dark argillaceous material.

The white masses in Fig. 55 are quartz grains; the large spotted mass extending from B 1 and 2 to E 1 and 2 is felspar; the black spots in A 3 and 4 are iron ores; the shaded fragment in A 2 is a piece of chlorite.

Attrition Test No. 126.

Loss per cent.	Dry test	7·52
	Wet test	18·26
	Average	12·89

No. 2.

SANDSTONE OR GREYWACKE.

CLEABARROW FARM, UNDERMILLBECK, BOWNESS-ON-WINDERMERE.

A fine-grained, compact, dark greenish-grey sandstone or greywacke, locally known as "Whinstone."

It consists of small subangular grains of quartz, about $\frac{1}{500}$ in. in diameter, with flakes of colourless mica and of chlorite about the same size. The chlorite gives the rock its slightly greenish colour. The only other ingredients of importance are iron ores and small grains of weathered felspar and a few zircons.

In Fig. 56 the flakes of mica and chlorite appear in section like minute white rods; the black spots are iron oxides; the remaining clear granules are quartz.

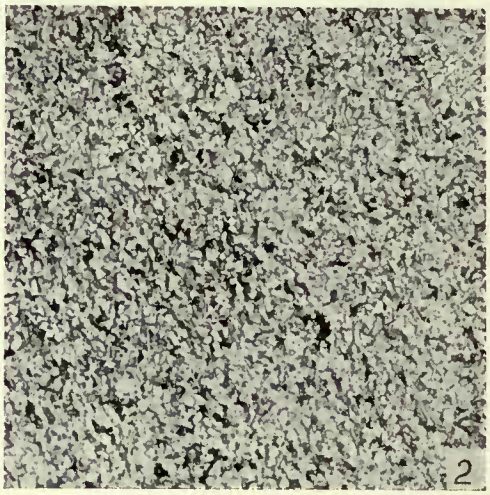


FIG. 56.

Attrition Test No. 2.

Loss per cent.	Dry test	6·20
	Wet test	13·38
	Average	9·79

No. 30.

IMPURE SANDSTONE
("Pennant Grit").

CRAIG-YR-HESG QUARRIES, PONTYPRIDD, GLAMORGANSHIRE.

A medium-grained, dark grey sandstone, which contains many small broken flakes of shale, with grains of quartz, felspar, iron ores, zircon, quartzite, and other rocks. There are also a few spots of calcite and flakes of white mica. The black shale gives the rock its dark grey colour. It is highly impure sandstone.

In Fig. 57 most of the white patches are quartz; the dark ones are mainly shale.

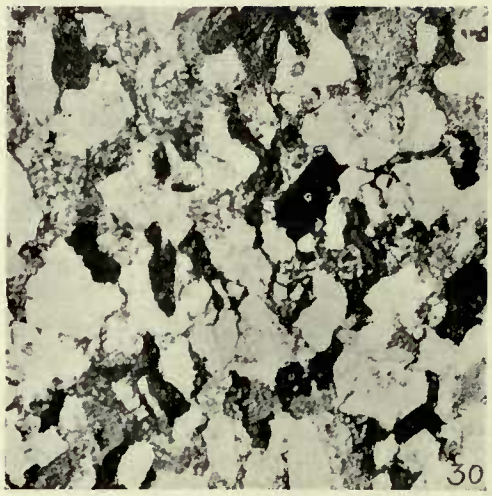


FIG. 57.
"PENNANT GRIT."

Attrition Test No. 30.

Loss per cent.	Dry test	14·45
	Wet test	27·54
	Average	20·99

Nos. 69 and 70.
IMPURE SANDSTONE.
DEE CLWYD, CORWEN, MERIONETHSHIRE.

A dark grey grit or impure sandstone, with grains of quartz, felspar, quartzite, slate, igneous

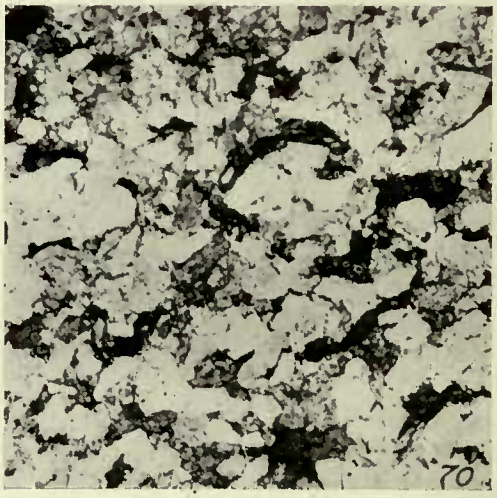


FIG. 58.

rocks, biotite, muscovite, chlorite, and a variety of other ingredients, cemented together by a small amount of a quartzose matrix. The rock is medium grained, compact, and free from cavities. All the

component grains are more or less angular, and the fine matrix fills the interstices.

The photomicrograph, Fig. 58, shows that there is a great similarity between this stone and No. 30; the materials are much the same, but in this stone they are more closely compacted.

Attrition Test No. 69.

Loss per cent.	Dry test	7·66
	Wet test	16·80
	Average	12·23

No. 122.

SANDSTONE
(" Blue " Paving Slab).

HIPPERHOLME, YORKSHIRE.

A pale grey, fine-grained sandstone, with slight traces of bedding. The grains are about $\frac{1}{200}$ in. in

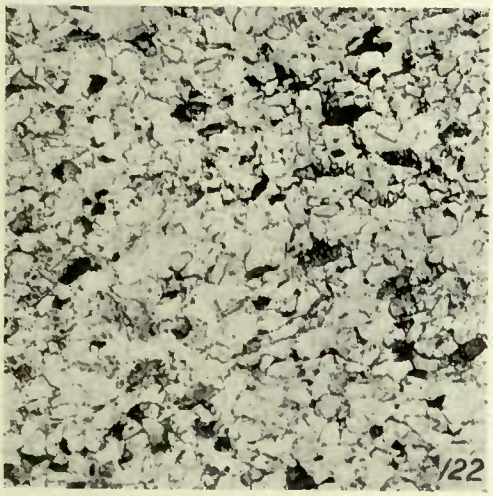


FIG. 59.
"BLUE" YORKSHIRE PAVING SLAB.

diameter, and are fairly angular, though always slightly water-worn.

Quartz is commonest, then orthoclase and plagioclase felspar (both frequently turbid with weathering). There is a little white mica in colourless scales, calcite in small irregular patches, and dark grains of iron oxide. The less important ingredients are tourmaline, zircon, and apatite.

The cementing material is siliceous and far from abundant.

In the photomicrograph, Fig. 59, which is taken by ordinary light, most of the dull grains are felspar, the clear grains are quartz; small rod-like sections of mica are seen here and there.

Attrition Test No. 122.

Loss per cent.	Dry test	12·89
	Wet test	23·92
	Average	18·40

No. 121.

SANDSTONE
(" Brown " Paving Slab).

BRADFORD, YORKSHIRE.

A fine-grained, pale yellow sandstone, with dark specks, occasioned by the presence of iron oxides. In the microscopic slide the average size of the sand grains is about $\frac{1}{200}$th of an inch, and they are mostly quartz, with a smaller quantity of somewhat weathered felspar, flakes of white mica, and a few little crystals of zircon. Every here and there the rock is blotched by the deposit of limonite or other hydrous iron oxides on the surfaces of the grains, giving them a dark colour and making them semi-opaque. This has partly resulted from the decomposition of original black mica, which has weathered into chlorite and limonite; chlorite is fairly common in some parts of the section. The grains are moderately well rounded, and are held together by a siliceous cementing substance, which is very inconspicuous. See Fig. 59.

Attrition Test No. 121.

Loss per cent.	Dry test	13·48
	Wet test	27·73
	Average	20·60

No. 123.

SANDSTONE
(" White " Paving Slab).

BETWEEN HALIFAX AND HIPPERHOLME, YORKSHIRE.

A greyish-yellow or brownish-yellow sandstone. The grains are about the same size as in the previous rocks, or very slightly coarser. Quartz greatly preponderates; then follow, in order of frequency, felspar (mostly orthoclase), white mica, iron oxides, weathered biotite, zircon, tourmaline, apatite. The yellow colour is due to a slight staining with limonite, which again has been partly set free by the decomposition of biotite. See Fig. 59.

Attrition Test No. 123.

Loss per cent.	Dry test	16·41
	Wet test	25·39
	Average	20·90

No. 85.

SANDSTONE.

JENKIN CRAGG QUARRY, KENDAL, WESTMORELAND.

A very fine-grained, dark-coloured sandstone, made up of small angular grains of quartz, felspar, iron ores, chlorite and muscovite. There is also a small amount of calcite in this specimen. The

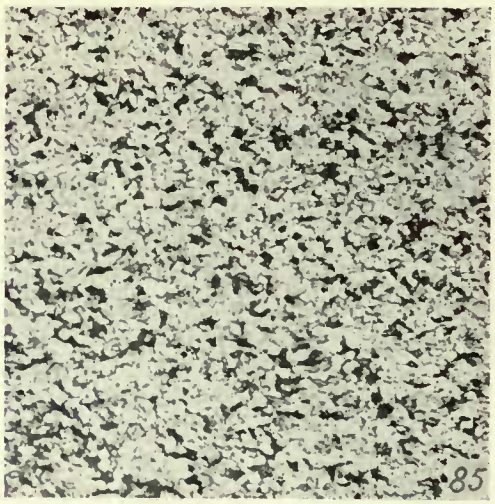


FIG. 60.

iron ores and chlorite give the sandstone its dark green colour, which probably accounts for its being known locally as "Whinstone."

In Fig. 60 the clear grains are quartz, the cloudy grains are felspar or chlorite, the dark spots represent iron oxide, the narrow elongated grains are mica.

Attrition Test No. 85.

Loss per cent.	Dry test	6·54
	Wet test	15·87
	Average	11·20

No. 78.

MICACEOUS SANDSTONE.

JENKIN QUARRY, KENDAL, WESTMORELAND.

A very fine-grained, dark grey, micaceous sandstone, composed of small angular grains of quartz, white mica, felspar, iron oxides, and chlorite. To the abundance of the last the dark colour is due. The mica may be readily observed in the hand specimen in the form of minute glistening specks.

The appearance of the micro-section is almost identical with that of Fig. 60.

Attrition Test No. 78.

Loss per cent.	Dry test	4·30
	Wet test	11·42
	Average	7·86

No. 110.

FELSPATHIC SANDSTONE.

HOUDAIN QUARRIES, CALAIS.

Rather fine-grained, grey, felspathic sandstone, consisting of sub-angular grains of quartz, felspar, felsitic material, &c., firmly cemented together by a siliceous matrix, so that the rock has many of the characters of a quartzite. There are also a few grains of zircon, white mica, tourmaline, and iron oxides. Fig. 61. Photographed in ordinary light.

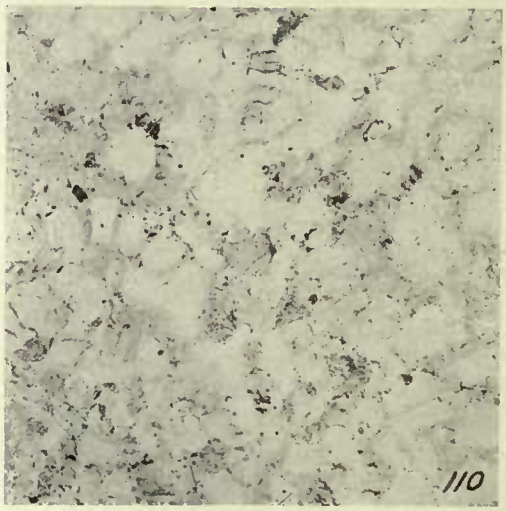


FIG. 61.

Attrition Test No. 110.

Loss per cent.	Dry test	10·11
	Wet test	13·38
	Average	11·74

No. 58.

FELSPATHIC SANDSTONE.

INGLETON, YORKSHIRE.

A dark green, rather fine-grained, felspathic sandstone, with grains of quartz and of felspar as the main constituents, along with a small quantity

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of epidote and chlorite, which give the rock its green colour.

There are also iron oxides, muscovite and calcite, though none of these is important. The sand grains are cemented and held together by an abundant, very fine, quartzose material, which appears dark in the figure, owing largely to the presence of the chlorite.

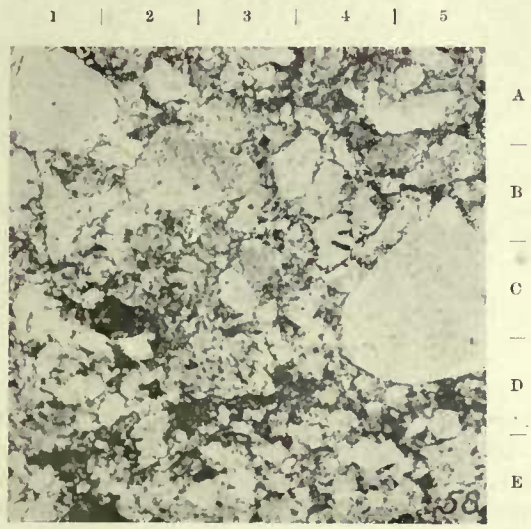


Fig. 62.

The photomicrograph, Fig 62, exhibits a portion of the rock in which the felspar grains greatly preponderate (other portions would have more quartz, as a rule); only a few grains of quartz are visible, B-C 4, C-B 2. The large grain in C 5 is composite, it is made up of several pieces of felspar, with a little quartz at the upper and lower ends; a small flake of muscovite lies near its upper left-hand edge.

Attrition Test No. 58.

Loss per cent.	Dry test	6·54
	Wet test	10·11
	Average	8·32

No. 111.

FELSPATHIC SANDSTONE.

Gorse's Quarry, Bury, Lancashire.

A felspathic sandstone, composed of rounded grains of quartz and felspar held together by a fine siliceous cementing material. Most of the felspar is orthoclase, but there is also some microcline and plagioclase; and muscovite, biotite, and iron oxides are present in very small quantity. See Fig. 63.

Attrition Test No. 111.

Loss per cent.	Dry test	36·86
	Wet test	53·12
	Average	44·99

No. 112.

FELSPATHIC SANDSTONE.

Gorse's Quarry, Bury, Lancashire.

This rock is essentially similar to the next, except that the average size of the grains is slightly greater. Fig. 63.

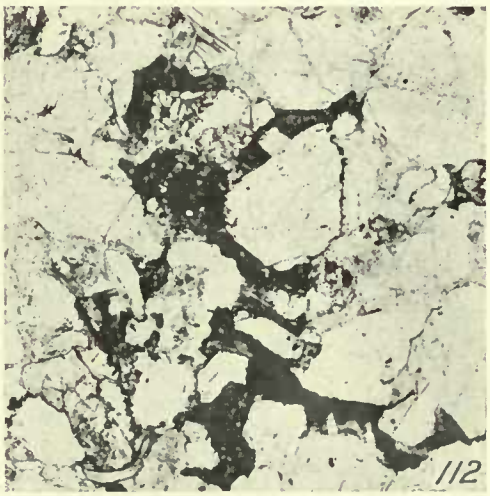


Fig. 63.

Attrition Test No. 112.

Loss per cent.	Dry test	28·51
	Wet test	50·68
	Average	39·59

No. 113.

FELSPATHIC SANDSTONE.

Leicester Mill Quarry, Chorley, Lancashire.

Rather coarse-grained felspathic sandstone, consisting of grains of orthoclase and quartz. Muscovite, microcline, plagioclase, biotite, zircon, and pieces of quartzite, are also present. The cementing material is siliceous, but here and there are patches of calcite. The slide shows one grain of brown tourmaline. See Fig. 63.

Attrition Test No. 113.

Loss per cent.	Dry test	19·92
	Wet test	30·08
	Average	25·00

No. 95.

CALCAREOUS SANDSTONE.

LIPHOOK QUARRIES, HANTS.

A yellowish-grey, rather fine-grained calcareous sandstone, locally termed "Bargate Limestone." It consists of rounded grains of quartz and felspar united by an abundant crystalline calcareous cement. There are also fragments of broken shells, Fig. 64 (A 1, A and B 2 and 3), foraminiferal tests, small aggregates of dark green glauconite (dark

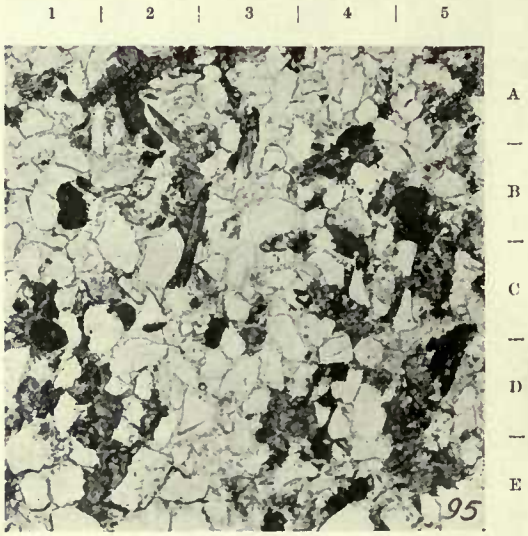


FIG. 64.
BARGATE STONE.

rounded grains (B 1, C 2 and 3), iron oxides, &c. The glauconite grains may be distinguished in the hand specimen as small yellow specks.

Attrition Test No. 95.

Loss per cent.	Dry test	9·47
	Wet test	25·17
	Average	17·32

No. 59.

CALCAREOUS SANDSTONE.

SCOUT BOTTOM, WATERFOOT, LANCASHIRE.

Calcareous sandstone, known locally as "Cank" or "Burnt Rock," consisting of small angular grains of quartz embedded in an abundant matrix of crystalline calcite. In addition to quartz, there are

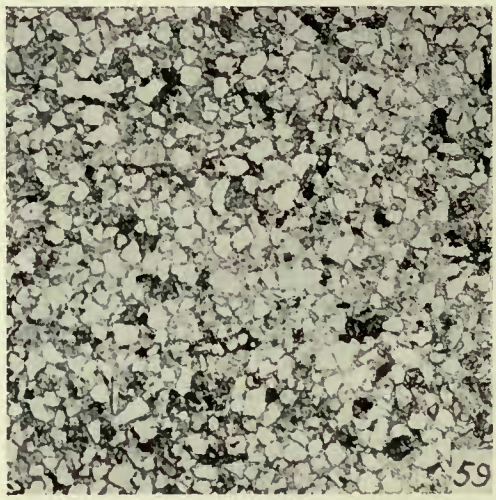


FIG. 65.
"CANK" OR "BURNT ROCK."

fragments of felspar, muscovite, iron oxides, and other minerals; but quartz greatly predominates.

Fig. 65 shows the angular quartz grains well separated from one another by the grey calcite matrix.

Attrition Test No. 59.

Loss per cent.	Dry test	8·01
	Wet test	15·23
	Average	11·62

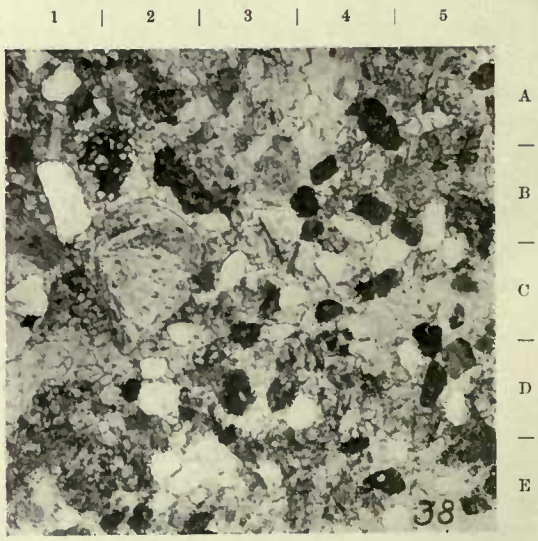


FIG. 66.
"KENTISH RAG."

No. 38.

CALCAREOUS SANDSTONE ("Kentish Rag").

COOMBE QUARRIES, MAIDSTONE, KENT.

A grey, impure, calcareous, glauconitic sandstone. The quartz grains are angular and form rather less than one-half of the rock. The calcareous matrix is irregularly crystalline, and scattered through it there are many small, rounded patches of green glauconite. Organic fragments are few, mostly bits of shells, foraminifera, echinoderms, and polyzoa (?). Small rounded black grains are present; they are probably iron oxides.

Fig. 66 shows the sparsely scattered white quartz grains in the abundant matrix of calcite; the large grain in B-C 1-2 is a fragment of a shell; the dark grain A 1-2 is a mass of glauconite containing grains of quartz; nearly all the other dark rounded spots are glauconite; in the hand specimen these appear as dull, dark-green specks.

Attrition Test No. 38.

Loss per cent.	Dry test	16·31
	Wet test	27·44
	Average	21·87

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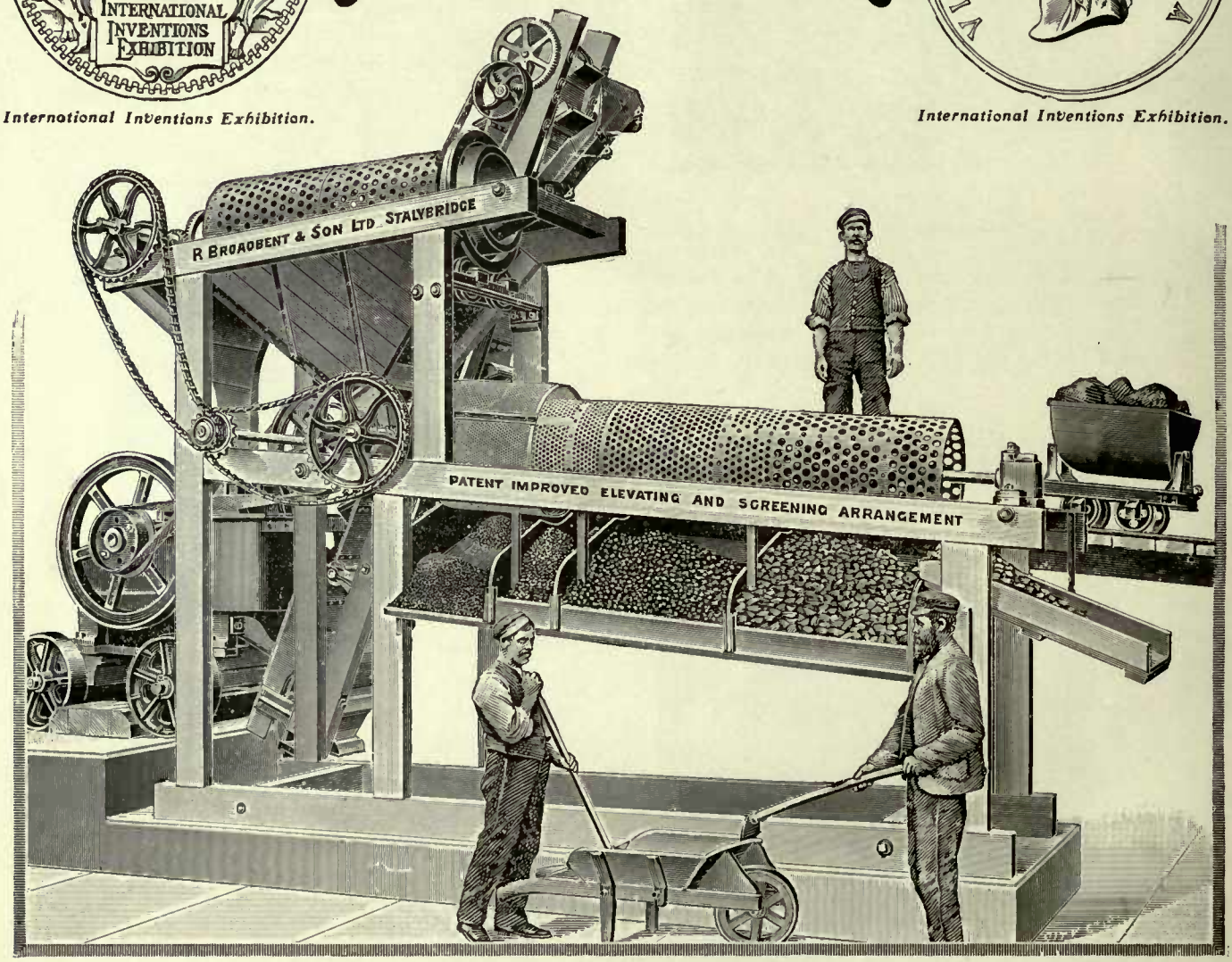


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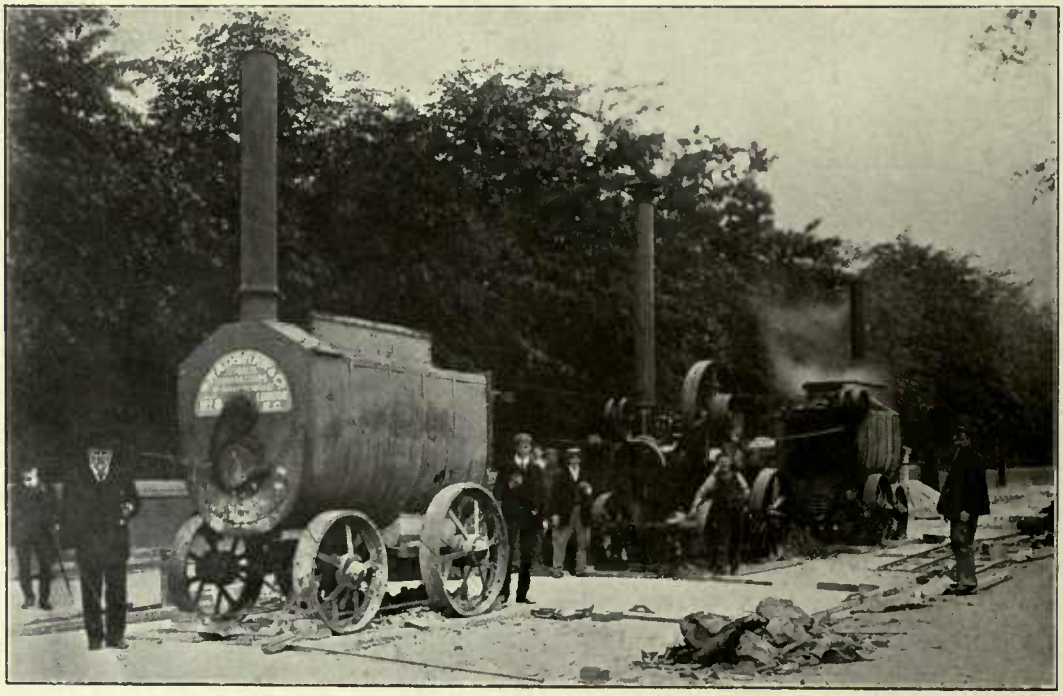
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No. 84.

LIMESTONE.

MONT VIREUX, FRANCE.

A compact dark grey stone, the small pale spots, varying in size from $\frac{1}{2}$ in. to $\frac{1}{4}$ in., are fragments of the stem and "arms" of crinoids; the dark grey

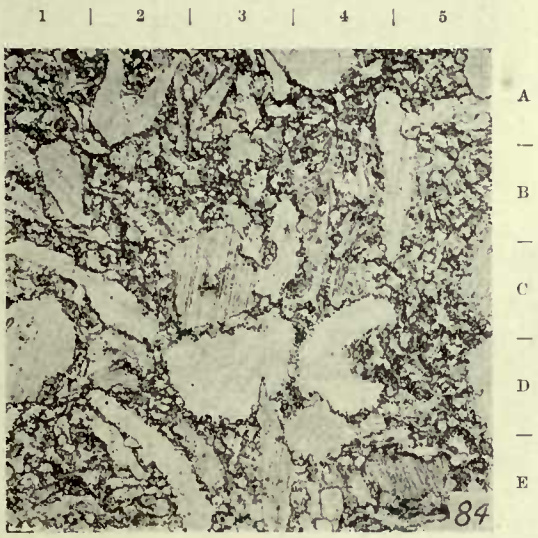


FIG. 67.

matrix in which these are embedded is made up almost entirely of still smaller *débris* of the same nature.

Very few of the fragments retain any of their original outline; solution has evidently proceeded to some extent before the consolidation of the stone (see the ragged edges of the clear patches, Fig. 67, C 3, D 3, and note how the jagged piece in E 3 penetrates the semi-circular one above it). The crinoid skeleton is made of carbonate of lime, and this partial solution of the fragments has provided the material which serves to cement the fine *débris* in the matrix, where some of it has recrystallised. It is a peculiarity of the crinoid skeleton that the separate segments are formed of single crystals of calcite; this fact may have an important bearing upon the life of the stone; the larger crystalline particles will resist weathering better than the fine granular matrix; on the other hand, the perfect cleavage of the mineral causes it to splinter under abrasive action. The cleavage may be seen in the shiny patches on the surface of the hand specimen, and in Fig. 67 it is the cause of the striated appearance, B 1, C 3, E 5.

Attrition Test No. 84.

Loss per cent.	Dry test	12·89
	Wet test	26·66
	Average	19·77

No. 104.

FORAMINIFERAL LIMESTONE.

("Blue" or "Mendip" Limestone.)

WINFORD, NEAR BRISTOL, SOMERSETSHIRE.

In the hand specimen this stone has a dark grey or brownish-grey colour; it has a rather crystalline appearance, due in a great measure to numerous fragments of crinoids (see No. 84). The fracture is roughly cuboidal.

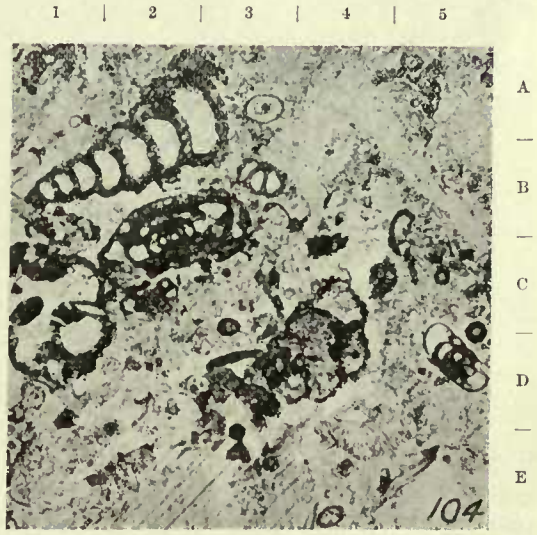


FIG. 68.
"MENDIP" LIMESTONE.

The microscope demonstrates that the stone is wholly composed of the fragments of calcareous shells of a variety of marine organisms; these include foraminifera in great plenty, crinoids, brachiopods, polyzoa, corals, and gasteropods. Most of

them have suffered fragmentation and partial solution, but the small shells of the foraminifera are often perfect (Fig. 68, A 2, B 2, D 5). Portions of crinoid stem, with the usual calcite cleavage, are seen in E 2 and E 3. The cavities in the shells are filled with clear calcite, and the same material in a granular and crystalline condition makes up the whole of the ground-mass.

Attrition Test No. 104.

Loss per cent.	Dry test	13·48
	Wet test	24·71
	Average	19·09

No. 35.

CRINOIDAL LIMESTONE.

BARTON, ST. MARY CHURCH, DEVONSHIRE.

A grey stone, slightly paler than 84 and 104; the large shiny faces of calcite are easily seen in the fresh fracture, which is rather irregular.

The stone is composed of broken crinoid stems of crystalline calcite; one large piece is seen in the lower part of Fig. 69, but the bulk of them have

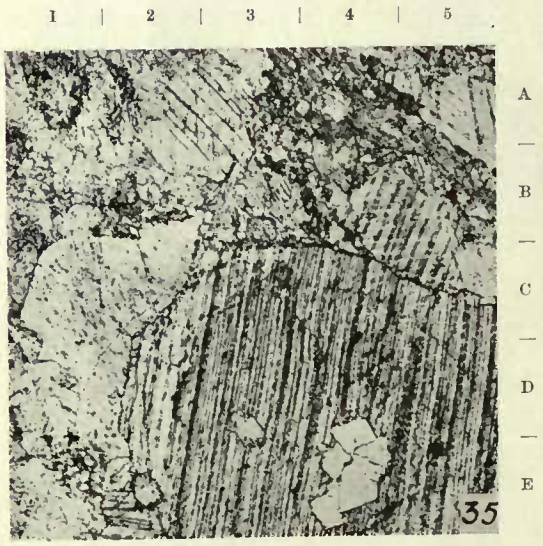


FIG. 69.

been deformed almost out of recognition by the crushing to which the stone has been subjected. The fragments are much larger than in No. 84.

Here and there a few rhombohedra of dolomite have made their appearance (Fig 69, E 4).

Attrition Test No. 35.

Loss per cent.	Dry test	17·53
	Wet test	30·71
	Average	24·12

No. 32.

CRYSTALLINE LIMESTONE.

WALLS HILL QUARRY, TORQUAY, DEVONSHIRE.

A close textured, pale grey stone, with a slight pinkish tinge. It is a highly crystalline limestone, in which the organic remains have been almost entirely obliterated by crystallisation, leaving only a few obscure and undecipherable traces. It is much sheared, and consists of alternating bands of coarser



FIG. 70.

and finer grains. Many of the crystals show the effects of deformation.

Sharply-defined crystals of dolomite are fairly numerous, and it is to these that the pinkish colour of the stone is due (Fig. 70, B 2-3).

Attrition Test No. 32.

Loss per cent.	Dry test	18·36
	Wet test	34·22
	Average	26·29

No. 33.

CRYSTALLINE LIMESTONE.

CHURSTON QUARRY, TORQUAY, DEVONSHIRE.

A streaky, grey and yellowish, fine-grained stone, with a dull sugary appearance on the freshly-fractured surface. Pale crystalline calcareous veins cross the stone in various directions.

The microscopic section shows a fine granular crystalline mass, with occasional coarser crystalline streaks; the fine-grained portion is very uniform in texture. Compression and shearing have

removed all traces of organisms. There are some large perfect rhombohedra here and there, probably dolomite (Fig. 71, B 4, an irregular crystal); the slight yellow iron staining of these crystals appear to be the cause of the colouration of the hand specimen.

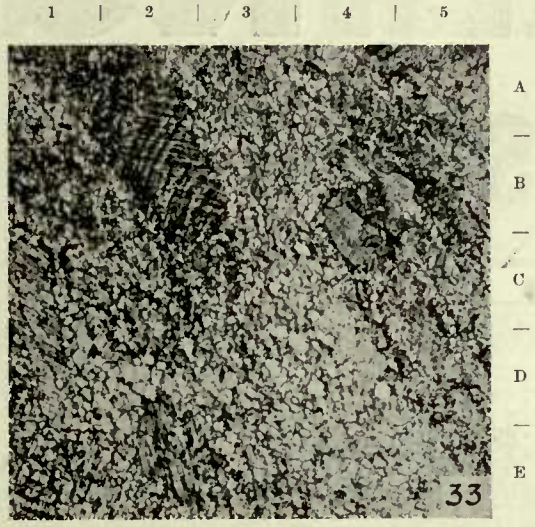


Fig. 71.

Attrition Test No. 33.

Loss per cent.	Dry test	16·31
	Wet test	33·64
	Average	24·97

No. 37.

MAGNESIAN LIMESTONE.

Churston Quarry, Torquay, Devonshire.

This stone is practically identical with No. 33, with this difference, that here the number of dolomite crystals has so much increased that they form an important part of the rock.

Attrition Test No. 37.

Loss per cent.	Dry test	14·79
	Wet test	29·05
	Average	21·92

No. 40.

DOLOMITE ("Rebb Stone").

Cattedown Quarry, Plymouth, Devonshire.

A fairly coarse-grained granular crystalline dolomite, which in the hand specimen has much the appearance of a creamy saccharoidal marble.

It is very largely composed of rhombohedral crystals, averaging about 5 mm. in diameter; between these there is an interstitial matter, also coarsely crystalline, but not in well-formed crystals. This is probably calcareous, for the rock effervesces, though only slightly, with weak cold acid. The rock is entirely recrystallised, its original condition being obliterated, and there are no fossils. It is also free from traces of shearing.

Fig. 72 shows the crystals of dolomite fitting closely together; their boundaries are often indi-

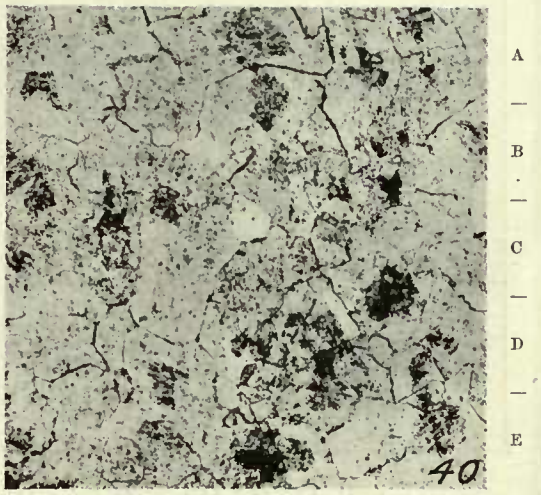


Fig. 72.
"Rebb Stone."

cated by dark lines, A 3-4, D 1. The dark spots are the middle portions of dolomite crystals, stained with iron oxides, C-D 4-5, E 3, A 1.

Attrition Test No. 40.

Loss per cent.	Dry test	16·45
	Wet test	33·64
	Average	25·04

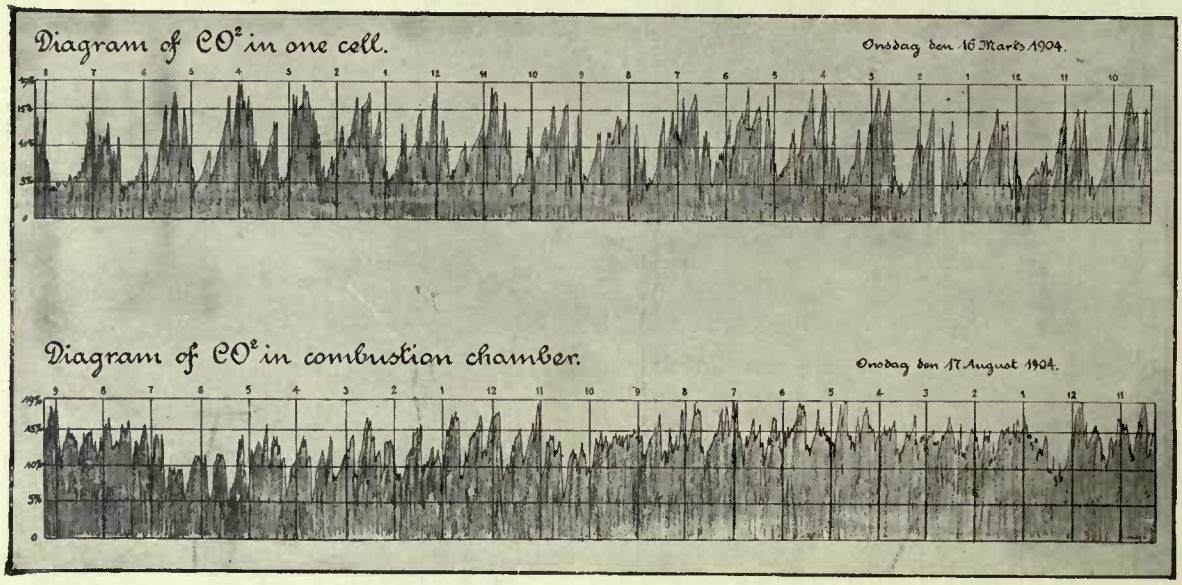
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FLINT.

Nos. 63 and 64.

PIT FLINTS.

FARNBOROUGH, BERKSHIRE.

A brownish-yellow flint, composed entirely of cryptocrystalline, extremely fine-grained silica, in which a few silicified foraminifera and other organisms are to be seen.

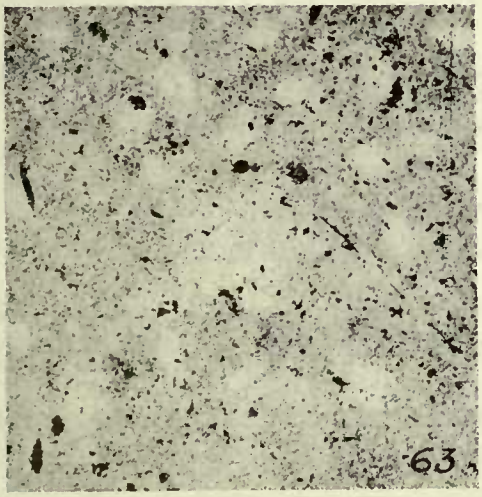


FIG. 73.

Most of the dark bodies seen in the figure are the iron-stained fragmentary remains of sponges and foraminifera. Fig. 73.

Attrition Test No. 63.

Loss per cent.	Dry test	8·54
	Wet test	8·79
	Average	8·66

Nos. 65 and 66.

PICKED SURFACE FLINTS.

FARNBOROUGH, BERKSHIRE.

Grey flint, with a white crust; similar in composition and structure to the preceding.

In the photomicrograph the white crust appears dark, Fig. 74; it is densest immediately in contact with the clear flint.

Attrition Test No. 65.

Loss per cent.	Dry test	10·98
	Wet test	12·30
	Average	11·64

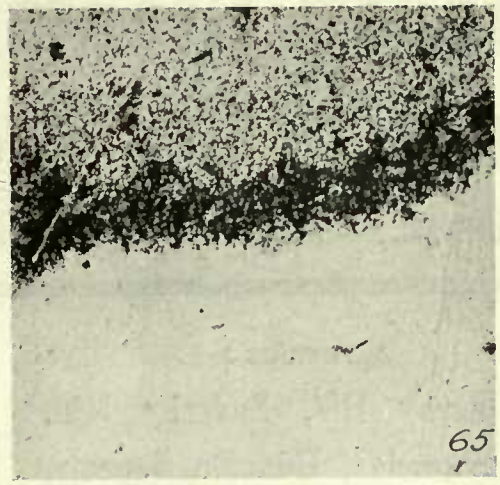


FIG. 74.

No. 94.

PICKED SURFACE FLINTS.

WHITCHURCH, HANTS.

Fine grey cryptocrystalline flint, with a few silicified fragments of organisms; mostly sponge spicules, which appear as paler spots and streaks in the ground-mass when seen in thin slices under the microscope. Fig. 75.

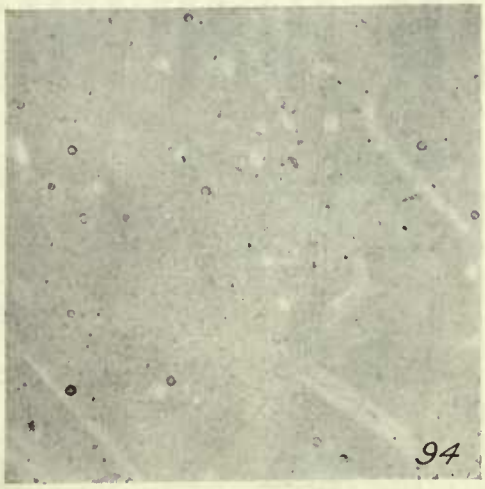


FIG. 75.

Attrition Test No. 94.

Loss per cent.	Dry test	8·25
	Wet test	6·74
	Average	7·49

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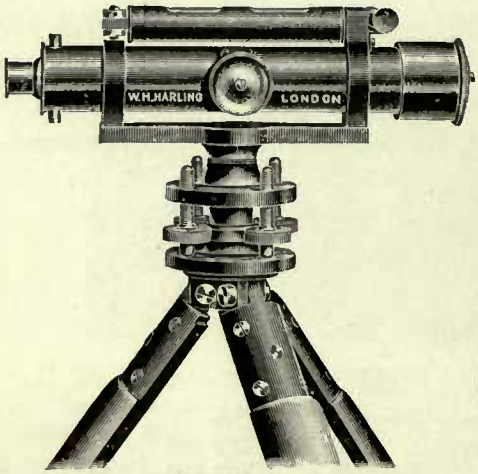
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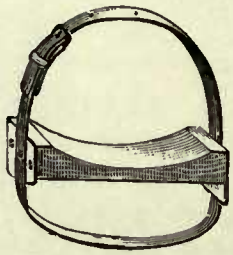
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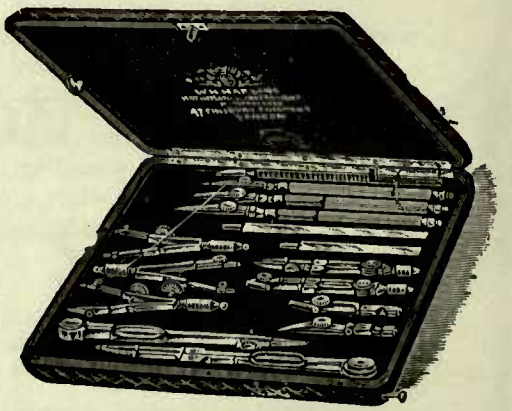
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DISCUSSION OF THE RESULTS.

In the foregoing brief notes each stone has been described separately. An attempt will now be made to summarise what appear to be the salient features of structure and mineral composition in each petrological group, and to show, if possible, the bearing of these characters upon the behaviour of the stones in the testing machine.

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DISCUSSION OF THE RESULTS.

GRANITE GROUP.

The average attrition result for thirteen tests in this group is 10; but it is fairly easily divisible into smaller petrological sub-groups, and if the averages for these are taken separately, more light is thrown upon their relative values; thus, five granite tests yield an average of 11·05, three gabbros give 10·06, three diorites 9·04, two hornblende gneisses 8·31.

From these figures one might be disposed to infer that the hornblende gneisses were the best resisters of the attrition action, the diorites next, and so on; but, as a matter of fact, the number of tests confined to a single type is still far too small to permit of generalisations of this kind; moreover, the numerical differences themselves are often unimportant, for they lie within the limits of experimental error.

In an examination of the bearing of the petrological characters upon the attrition results in this group three prominent factors stand out. They are: (1) Texture, (2) the kind of mineral, (3) the state of freshness of the minerals. With regard to the first of these, it is evident that fineness and evenness of grain is an advantage, and that coarse grain or porphyritic structure is disadvantageous. It is on account of the *granitic texture* that the rocks of this group, taken as a whole, are not higher in the attrition scale.

The influence of the kind of mineral (2) is not so easy to determine, but, other things being equal, a high proportion of hornblende appears to be favourable to resistance; quartz in a like manner is favourable because of its hardness and lack of cleavage.

Fresh unaltered original minerals are not absolutely essential to a high capacity to resist abrasion; the two stones that take the best position in the test scale for this group are considerably altered —the felspars are decomposed, and their substance is a mixture of smaller mineral units; the ferromagnesian minerals have changed to chlorite and to fibrous uralitic hornblende.

Alteration of the minerals in the rocks of this group appears to have a toughening effect, which is probably due to reduction in the size of the component grains, together with a greater felting and interdigitating of the crystals. A very important feature in the best rocks is the late crystallisation of quartz or the production of secondary quartz in a kind of ground-mass, which serves to bind the whole together with a hard, resistant material.

It is possible for fresh felspar to behave fairly well in the test when the grains or crystals are small and are closely matted together.

PORPHYRIES AND PORPHYRITES.

The stones that fall into this petrological group take a higher place in the attrition tests than those in any of the other groups. This seems to be due to the regular distribution of quartz throughout the ground-mass of the rock, associated with felspar, either in a micrographitic (100) or in a micropegmatitic structure (115). The ferro-magnesian minerals occupy a quite subordinate place in these rocks.

When the test results of these rocks are compared with those of the granites, which consist of the same minerals, but in larger grains, their superiority is manifest. It is an excellent example of the importance of rock structure. The fine-grained ground-mass, or matrix, in which the larger crystals lie, consists of quartz and felspar, usually imperfectly crystallised, forming a dense "felsitic" aggregate. Hence there are no natural cleavages or planes of weakness within the rock which will open up and allow the stone to crumble.

It is not at all necessary that the felspar should be fresh; in the best stones it is cloudy, altered, and often stained by iron oxides.

A small amount of decomposition, by the production of additional quartz, which acts as a cementing material, and of fibrous scaly muscovite, which resembles a feltwork, instead of being disadvantageous may operate in a contrary way, improving the toughness and durability of the stone.

BASALT, DIABASE AND DOLERITE GROUP.

Considerable difficulty is experienced when an attempt is made to correlate petrological facts with the test results in this complex group of rocks. This is due in part to the impossibility of sharply

defining petrological species; border-line varieties occur which embrace the characters of more than one rock type. For instance, certain diabases from North Wales are extremely variable within moderate limits, and approach the porphyrites. These rocks of the porphyrite type seem capable of resisting the attrition action with pre-eminent success; this appears to be due to the fine grain and regular size of the mineral constituents, and more particularly to the micropegmatitic arrangement of the quartz and felspar throughout the ground-mass. The precise influence of the enstatite, which is largely altered to bastite, cannot yet be ascertained. Although these rocks resemble porphyrites, their mineral composition has led to their being placed by many petrologists among the "quartz-diabases."

Among the more typical members of this group the ophitic structure is no doubt a factor of importance; it appears that stones with smaller augite units are better than those with larger ones, and as a general rule the coarser grained stones take a lower place than the finer ones.

With regard to alteration of the minerals, it is important to distinguish between two kinds. If the original augite has been altered to chlorite and calcite, the result is usually a poor rock; but if the alteration product is fibrous uralite, the result seems to be even better than with fresh augite. Other things being equal, the decomposition of felspars does not produce adverse results; but this depends entirely upon the nature of the alteration products—epidote, albite, quartz, mica are not bad, while calcite and kaolin generally are.

The *rôle* of olivine as regards the attrition test is not clear; it is found in one of the best rocks of the group in a very fresh condition, and in some of the worst rocks in a highly altered condition. The probability is that in all cases it is a source of weakness in the stone. Much depends on its abundance of freshness; if it has passed into serpentine, chlorite, limonite and carbonates it is disadvantageous, at least if it occurs in numerous large units.

ANDESITES.

Among the andesites, fine grain, with complete felting of the felspar laths, produce the most resistant stone. A fluxional arrangement of the felspar laths, whereby they are given a uniform orientation, is inferior to the felted structure in wearing capacity. Markedly porphyritic structure is a detrimental quality. This group of rocks is large and diverse; its members consist very largely of felspar, and hence, unless the crystals of the ground-mass are small and well felted together, the attrition tests are only moderately good. The absence of quartz has an important effect in diminishing the hardness (cf porphyrites). If calcite and limonite abound in the rock as alteration products it cannot yield good results.

HORNFELS.

Too few of the rocks of this group have been tested to make the results generally applicable. Their structures and minerals vary so greatly that the few tests included in the table are quite insufficient to show what place the group would hold as roadstones. On the whole it is clear that the hornfelses are above the average. The heating which they have undergone has driven out part of their water of composition and re-crystallised many of their minerals; hence the grains are usually fresh and comparatively hard. But hornfelses are well known to be rather brittle, probably a consequence of their evenly granular texture. It is interesting to compare Nos. 127 and 130, two weathered diabases, with No. 128, a granular hornfels formed by heating a similar rock. The hornfels is the freshest of the three, but it is evidently rather more brittle; all three rocks, however, are excellent. Apart from the structure, hornblende seems preferable to biotite as an important ingredient.

QUARTZITES AND SANDSTONES.

These two types of stone have been classed together on account of their similarity of composition and the impossibility of sharply delimiting one from the other. Notwithstanding this, a glance at the attrition tests makes it evident that the quartzites constitute a class by themselves; they are all gathered at the head of the list, and their average attrition result is 5·5, the average of the remaining sandstones is 18.

The superiority of the quartzites over other members of the group lies in the complete cementation of the grains by quartz, the same material as the bulk of the grains themselves; the result is an intensely hard, fairly homogeneous body, free from pores. The size of the grain appears to be a factor of quite subordinate importance in quartzites and sandstones. Of the three sandstones that approach nearest to the quartzites in the attrition tests, two are very fine-grained, even-textured and thoroughly-compacted stones, with an abundant supply of microscopic mica and chlorite flakes forming a

felted mass among the tiny quartz grains; the third sandstone is much more uneven in grain, and the grains vary in their nature, but there is a large amount of fine siliceous cementing matrix, and the stone is thereby rendered compact.

The pre-Silurian and Silurian sandstones are better than the Carboniferous ones among those tested, but from our knowledge of the microstructure of samples not included here, we can say that this is not a rule of universal application.

Generally speaking, unless there is a good siliceous matrix all varieties of sandstone fail in the tests, whether their constituent grains are large or small and whether they are heterogeneous or similar in kind.

LIMESTONES.

The low position occupied by the limestones in the test series is readily accounted for by their greater softness as compared with the other stones. The dolomites, magnesian limestones, and pure limestones have been classed together for our present purpose, because the passages from one to the other are so gradual.

If we take the pure dolomites alone, it is clear that those behave best in the attrition test which have a fine-grained, even, granular texture, with irregular-shaped grains interlocking closely one with another, and with a general absence of porous cavities. A dolomite is by no means always better than a limestone, but the best type of dolomite will be more resistant than the best limestones, being harder.

Among the limestones, those stand highest that are composed of a mixed assemblage of small organic remains, notably of foraminifera, and possess at the same time a somewhat bituminous composition (this characteristic is often associated with foraminifera in Carboniferous limestone). Crinoidal limestones do not stand so high, evidently on account of the ready cleavage of the particles of calcite, which is not only a soft mineral but has an extremely perfect cleavage, hence it wears rapidly and crumbles easily under repeated small blows; but if the crinoid fragments are small and uniform in size, set in a matrix of fine calcareous matter, the stone may compare well with other limestones.

FLINTS.

With rocks that possess such uniformity of structure and of chemical composition as the flints, the utility of a microscopic examination of thin slices ceases to exist. In other words, we are at present quite unable to point to any differences of texture or structure in the flints that appear to be connected in any way with the behaviour of different samples of these stones in the testing machine. It is quite possible that after testing and slicing a great number of samples some hitherto unobserved microscopic character might be detected which would explain the differences of behaviour; no such character has yet been noticed.

On looking over the samples of tested flints no essential differences of angularity, colour, or form can be seen; perhaps the presence of more or less quarry water may account for something. It is important to bear in mind the fact that "surface" flints, just as well as "pit" flints, may contain quarry water. It is usually regarded as an established fact that "surface" flints are superior to "pit" flints for road purposes; so far as attrition goes, this is not supported by the test results, and the explanation of this divergence from the accumulated experience of many surveyors is probably this: many of the consignments of "surface" flints do not really possess the best properties of the "surface" variety, although they are certainly not "pit" flints. The weathering of a flint, whereby a good "surface" flint is produced, consists in the removal of its quarry water, the removal of some of the soluble colloid silica from between the minute microlites of crystallised silica, and to some extent the introduction of more of the latter substance into the minute interstices in the form of a cement. If these changes have not taken place in the stone it is immaterial whether it is styled "surface" or "pit" flint. The presence of quarry water in a stone rendered slightly porous will tend to weaken its resistance to repeated blows (*vide* porosity).

Once the sharp edges of the flint are worn away, its natural hardness causes it to take a very high place in the attrition tests (64 and 66), but to this rounded condition of the stone there are objections in practice with which we are not here concerned.

VALUATION OF THE NUMERICAL RESULTS.

Too much reliance must not be placed upon the exact numerical value of the test results; from the nature of the case *absolute* measurements are impossible. Some of the results cannot be immediately explained on petrological grounds. The reasons for this are numerous; some of them may be mentioned here. The *number and size* of the individual stones in a test batch, although kept as nearly regular as possible, may yet vary sufficiently to cause some difference. The *angularity* or *roundness* of the stones is a factor which certainly influences the result; rounded stones wear more slowly, as was pointed out by Daubree. This fact is very clearly brought out in the duplicate flint tests (see table of attrition tests). The *temperature* at which the test is made may have a sufficiently wide range of variation to produce slight differences in the tests. *Quarry variations* are perhaps the most important; from the same quarry the quality of the stone undoubtedly varies from time to time, and it is quite unlikely that a test from a certain quarry repeated, say, two years hence would give identical results. The stone also varies from bed to bed, often both horizontally and vertically; or the variation may occur rapidly and irregularly from spot to spot in the case of many apparently homogeneous masses of igneous rocks.

But in spite of several apparently anomalous results, the general reliability of the tests is amply confirmed by the petrological examination of the stones, and this is emphasised by the fact that so many highly favoured stones occupy prominent places in the list.

The following diagram, Fig. 76, will serve perhaps better than words to show the relative position of the different groups of stone when arranged according to their powers of resistance to the action of the attrition testing machine. In each case the ten highest results are taken for each group, except where a smaller number were actually tested.

Stated in another way, the results stand thus:—

Petrological Groups.	Number of stones tested.	Attrition Results.		
		Highest.	Lowest.	Mean (approx.).
Quartz-Diabases	4	2·66	5·47	3·82
Diabases, Dolerites and Basalts	21	3·42	29·93	12·73
Porphyries and Porphyrites ..	14	3·71	13·50	6·7
Granitic Group	13	6·61	15·23	10
Granite	5	6·61	15·23	11
Diorite	3	7·49	9·94	9
Gabbro	3	9·08	10·74	10
Gneiss	2	8·03	8·59	8
Andesites	4	5·92	15·68	10
Hornfels	4	6·47	8·05	7·5
Sandstones and Quartzites .	23	3·73	44·99	15
Quartzites ..	5	3·73	7·30	5·5
Flints	11	7·49	13·38	10
Pit Flints	5	7·81	10·62	9
Surface Flints	6	7·40	13·38	10·5
Limestones	11	11·13	33·89	20

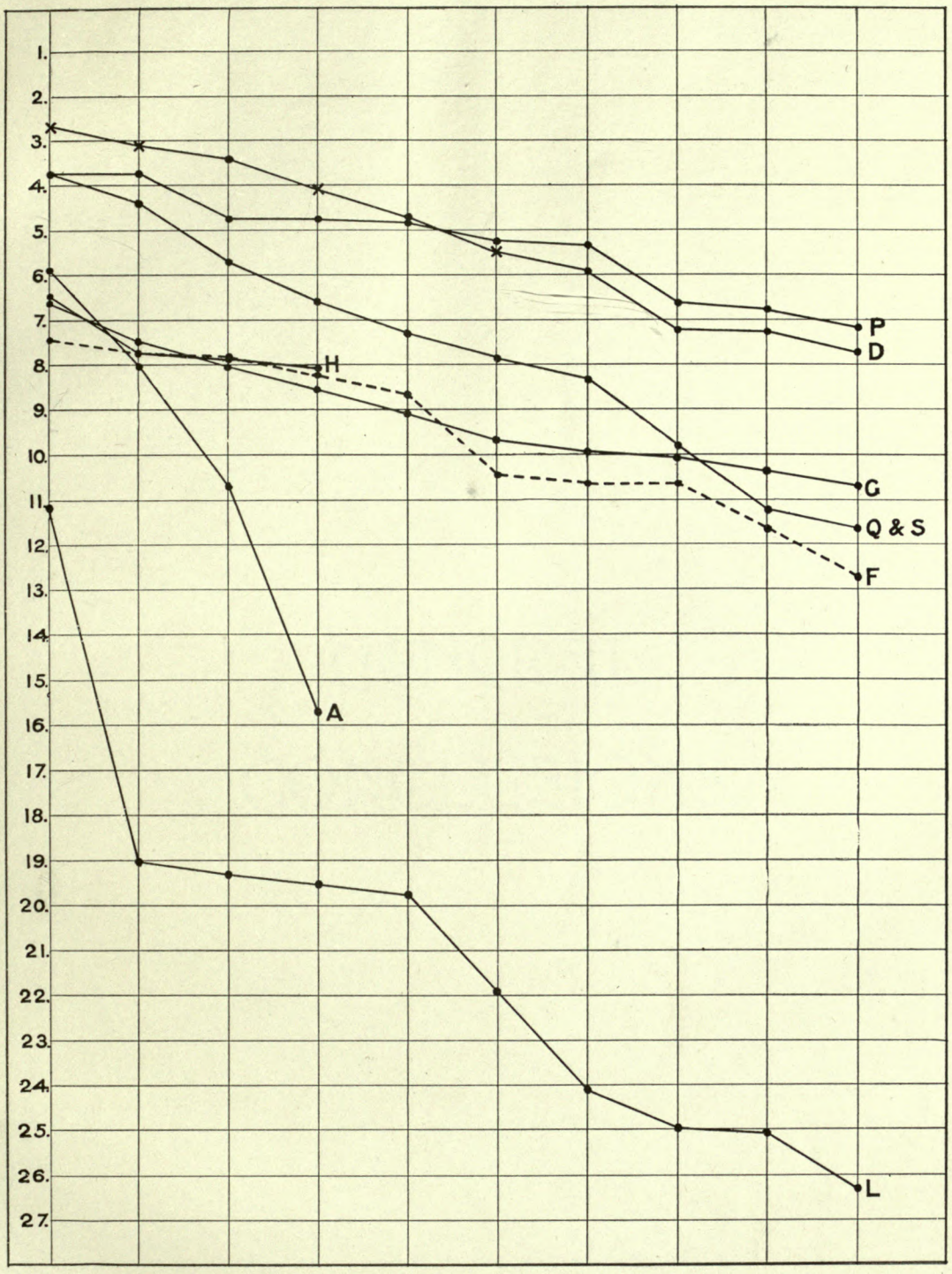


FIG. 76.

DIAGRAM TO ILLUSTRATE THE RELATIVE POSITION TAKEN BY THE ROCK-GROUPS IN THE PRESENT SERIES OF TESTS.

The figures in the left-hand column represent the average percentage loss in dust (wet and dry tests).

A=The Andesite group. D=The Diabase and Basalt group (the crosses × indicate quartz-diabases, very similar to porphyrites).
F=Flints. G=The Granite group. H=Hornfelses. L=Limestones. P=Porphyries and Porphyrites.
Q and S=Quartzites and Sandstones.

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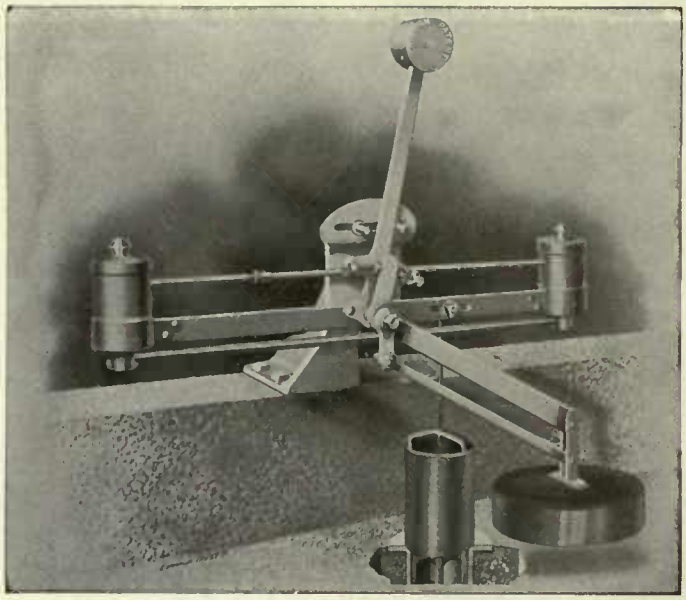
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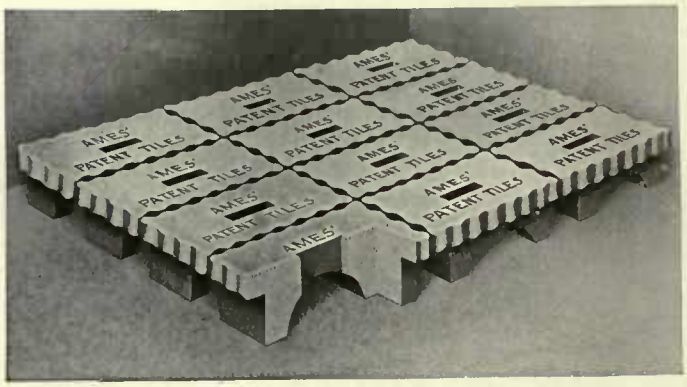
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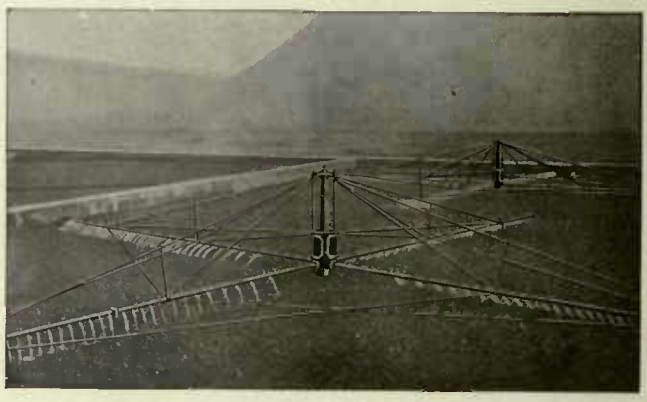
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GENERAL CONCLUSIONS.

Enough has been said to show that each type of rock must be judged by its own criteria; the classification of the roadstones in Fig. 76 does not imply that only those should be laid down that are represented by the higher curves, each stone—even the frequently maligned limestone—has its place in road economy. But the attrition tests, enforced by a knowledge of the mineral composition and structure of the stone, indicate most clearly what are the best varieties of stone in each group.

It is still premature to attempt to draw any sweeping conclusions; before this can be done more stones must be tested and examined from some of the groups that are as yet only poorly represented. There are, however, one or two points which are worthy of attention. It is well known that the hardness and toughness of a stone depend upon the hardness and toughness of the mineral constituents, and upon their mutual relationships. The hardest and toughest stones combine *abundance of a hard mineral—e.g.*, quartz—with a *dense fine-grained texture.*

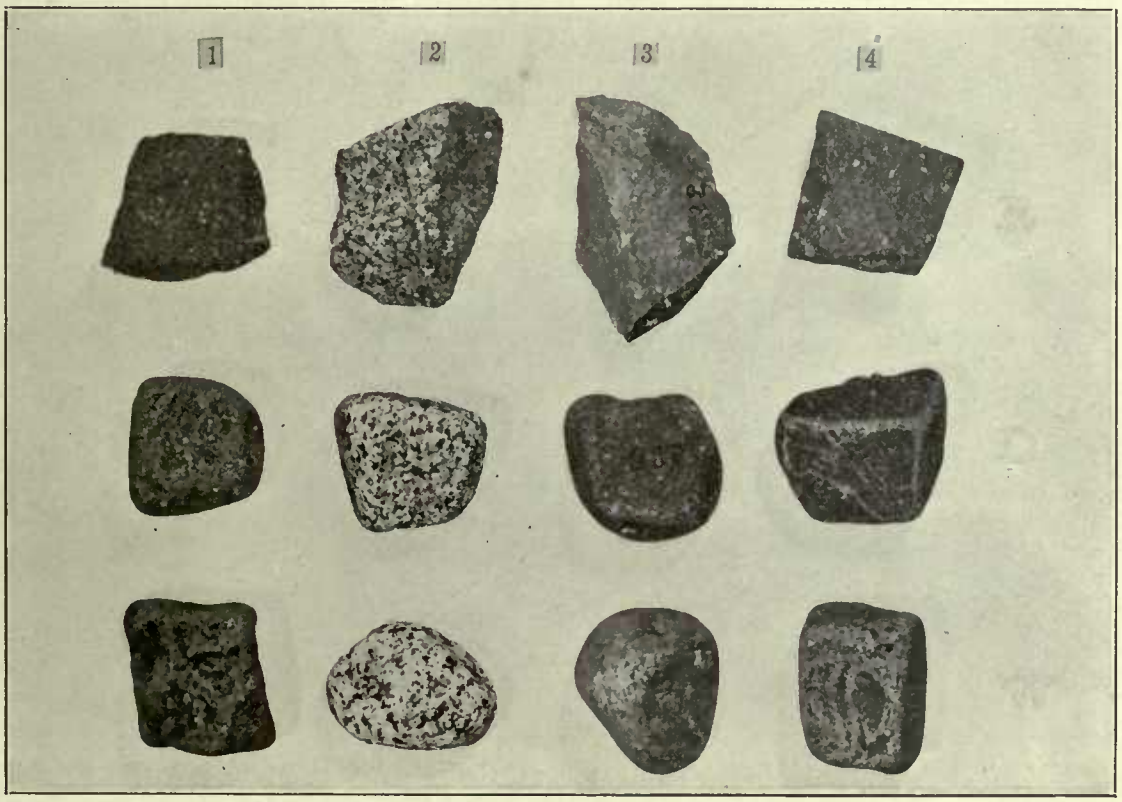


FIG. 77.

PHOTOGRAPH OF FOUR ROAD STONES TO SHOW THEIR APPEARANCE AFTER UNDERGOING THE ATTRITION TEST.

R=The rough stone. D=The result after the dry test. W=The result after the wet test. 1=A Porphyrite. 2=A Granite. 3=An Iron Slag. 4=A Hornfels.

The best rock structures for wear are the micro-pegmatitic (or micrographic), the microgranitic, and the ophitic. In the last-mentioned structure a framework of augite binds together the felspar crystals, and the smaller the augite units the better the result. The two other structures are similar in

this respect—*viz.*, that they present a fine-grained mixture of quartz and felspar, intimately related and bound together into a dense hard mass.

Porosity.

Whatever is conducive to porosity is disadvantageous, whether it be the absence of cementing substance between the grains or a tendency in one of the mineral constituents to cleave. This influence of porosity in producing low attrition results may be seen in comparing the "wet" of minerals (granite, diabases). These facts point to the action of the incompressible water exerting a disruptive pressure within the crevices with every blow and shock. The bearing of this point upon the waterproofing of porous stones might be borne in mind.

Fresh and Altered Rocks.

There is much confusion among practical men unacquainted with petrology, arising from an improper conception of the meaning of the terms

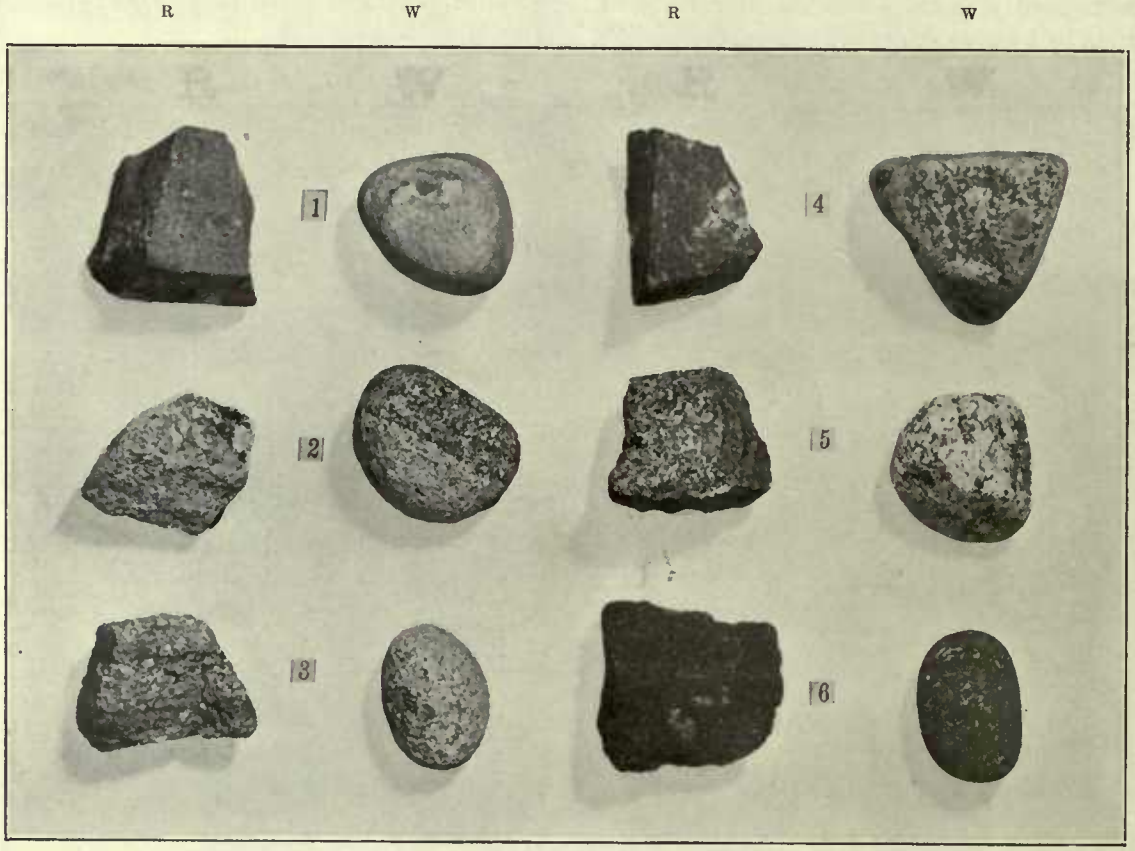


Fig. 78.

Photograph of Road Stones to Illustrate Cases of Wear after Undergoing the Attrition Test.

R=The rough stone. W=The result after the wet test. 1-3=Sandstones. 4=A good Diabase. 5=A coarse Granite. 6=A poor Dolerite.

with the "dry" tests. With few exceptions the "wet" tests yield the higher values of dust. The exceptions are mostly flints and quartzites—*i.e.*, rocks which are not porous. The difference is greatest in porous rocks (sandstone), rocks with minerals that have good cleavage (limestone, dolomite, granite); rocks with soft minerals easily split open (diabases, weathered basalts), rocks with a variety "fresh," "altered," "decomposed," as they are applied to rocks or the minerals composing them.

If we use the terms "fresh" and "decomposed" = rotten, we in general convey the ideas of goodness and badness respectively; this is not the case when reference is made to rocks. When we speak of a mineral being in a fresh condition we mean

that it possesses its inherent properties in an unimpaired state; if the original or primary minerals are not altered by subsequent processes they are said to be "fresh." A fresh *rock* is one in which the minerals that compose it are fresh. When a mineral within a rock alters or is decomposed as the result of certain forces acting upon it, it breaks up usually into one or more *new minerals*, each one in its own way being as "fresh" as the original mineral.

It is possible for the alteration of a rock to make it actually stronger than before. Some of the new minerals produced by alteration (molecular rearrangement) may be an improvement upon the original; others may be the reverse. When a rock is acted upon by surface weathering agents it frequently happens that certain selected mineral substances are removed, and it is thereby weakened, or softer minerals are introduced.

For this reason it has been suggested that the term "decomposition" should be confined to surface weathering, while "alteration" is maintained for more deep-seated molecular rearrangements within the rock; but the suggestion is not regularly acted upon.

The microscopic examination of the rock shows what the action of the alteration is, and whether it is likely to be beneficial or not in its effects; thus the alteration of augite to chlorite produces a result that is usually inferior to the original in wearing properties, while the alteration to uralite appears to be superior.

The very best rocks in these tests are altered rocks, and as a general rule a certain amount of alteration of the felspars seems to be an advantage. The reason for this is that the alteration produces a *number* of mineral units where formerly only *one* existed; in other words, the texture is made finer and often the interlocking of the grains is made more complete. A large fresh crystal of felspar, by its rigidity and perfection of cleavage, is less able to resist impact than the same volume of substance in the condition of an intimate mixture of granules of mica, sericite, kaolin, or epidote,



Fig. 79.

Cases Containing the Collection of Road Stones: Card Catalogue and Files: Museum of Practical Geology, London.

especially if they are united by a quartzose cement, as is frequently the case.

In short, alteration by reducing the size of the grains and felting them more closely tends to enhance the *toughness* of the stone. It is only when large quantities of soft minerals are introduced, or some ingredient is removed, usually by surface agencies, that alteration is liable to be inimical to the wearing properties.

Fineness of grain makes for toughness in all classes of stone. A stone made of heterogeneous particles or minerals will wear better in a fine-grained condition than when coarse, but if the grains are somewhat large, provided they are fairly uniform in size and held together by a fine matrix, the stone may wear as well as a finer-grained one.

Great care has been taken in the foregoing notes to avoid complicating the present issue by references to any of the stones in road practice. We have set ourselves to examine what light could be thrown upon the attrition tests by the microscopic examination of the stones. Notwithstanding certain evident imperfections, we are satisfied as to the practical utility of combining these two testing instruments, and we believe that, after working carefully through the series of stones with the microscope, it is possible to forecast the behaviour of a new stone, from the thin section, with very fair accuracy.

In order to illustrate the action of the attrition test on roadstones two photographs are here reproduced, Figs. 77 and 78.

The photograph Fig. 77 requires little explanation; the more perfect rounding of the stones after the wet test is clearly shown (the apparent exception in 1 D is due to the foreshortening of the cuboidal block); the slight rounding of the edges only in 4 D is very evident. Nos. 1 and 4 take a much higher place in the scale than do Nos. 2 and 3.

In Fig. 78, with the exception of No. 4, which is an example of a highly-resisting stone, all the specimens represent cases of extreme wear; the contrast between 4 and 6 is particularly noteworthy. A large white felspar crystal (a source of weakness) may be observed in the tested specimen of No. 5.

(N.B.—It should be noted that in Figs 77 and 78 each stone is a separate individual.)

Any of the specimens mentioned in these notes may be referred to and examined at the Museum of Practical Geology. Fig. 79 is a photograph of the stored collection; it also shows the card index and the file of notes wherein all useful information relating to the stones will be registered as it comes to hand.

A GLOSSARY

OF TECHNICAL TERMS EMPLOYED IN THE DESCRIPTIONS OF THE ROAD METAL.

ACICULAR.—Needle-shaped; sharp-pointed.

ACTINOLITIC.—Resembling actinolite, a fibrous variety of hornblende.

ANDESITE.—A volcanic lava, intermediate in character between acid and basic, and consisting principally of plagioclase felspar and ferromagnesian minerals, usually without olivine.

BASALT.—A black, compact rock; a basic lava which was either ejected on the surface or as a mass which consolidated below ground. It consists essentially of plagioclase, augite and olivine, and is sometimes porphyritic. It often contains some uncrystallised, glassy substance in the ground-mass.

BRACHIOPODS, or "LAMP-SHELLS."—A class of bivalve shells. The valves are placed on the back and front of the animal, in distinction from the right and left sides as in the case of lamellibranchiata (mussels, &c.).

CALCAREOUS.—Composed of or containing calcium carbonate (limestone).

CATACLASTIC.—Internally fractured or crushed by pressure.

CHLORITISED.—Altered to chlorite.

CLASTIC.—Composed of broken fragments or grains cemented together. Characteristic of most sedimentary rocks.

CRINOIDAL.—Composed more or less of crinoids—*i.e.*, globular or cup-shaped organisms, with jointed arms growing on a jointed calcareous stalk.

CRYPTOCRYSTALLINE.—Very finely (minutely) crystalline.

DIABASE.—A compact, massive, dark green, intrusive igneous rock, chiefly composed of labradorite, augite, and sometimes olivine. It is distinguished from basalt by having consolidated at a greater depth and in greater masses, and in being thoroughly crystalline, generally non-porphyritic and often ophitic. (See dolerite.)

DIORITE.—A plutonic rock consisting essentially of oligoclase, andesine or labradorite felspar and hornblende, augite or biotite.

DOLERITE.—Resembles basalt in composition and occurrence, but is usually less porphyritic, more thoroughly crystalline, and coarser in texture. Often used synonymously with diabase.

DOLOMITE.—Calcium and magnesium carbonate. Magnesian limestone.

ECHINODERMATA.—A group of marine animals which comprises crinoids, star-fishes, sea-urchins, &c.

EPIDIORITE.—A variety of diabase in which hornblende has arisen from the decomposition or alteration of augite.

FELSITE.—An igneous rock possessing a fine texture, and generally consisting of an intimate mixture of felspar and quartz.

FELSITIC.—A term applied to rocks showing the characteristic close grain of felsites.

FELSPATHIC.—Containing felspar.

FERRO-MAGNESIAN.—Minerals containing iron and magnesium. Those chiefly referred to are augite, biotite, hornblende and olivine.

FLASER.—A term derived from the German and applied to structure showing patches of broken minerals arranged in fine streaks.

FLUXION STRUCTURE.—Fluidal. Structure indicative of a flowing motion in the rock previous to its consolidation.

FOLIATION.—The arrangement of minerals in irregular bands, or laminæ as in schists.

FORAMINIFERA.—Microscopically minute creatures having a calcareous shell pierced with fine holes, through which filaments protrude. Abundant in chalk.

GABBRO.—A plutonic thoroughly crystalline rock, consisting essentially of plagioclase felspar, and a pyroxene (generally diallage).

GASTEROPODA.—Univalve, snail-like molluscs, such as whelks, periwinkles, limpets, &c.

GLOMERO-PORPHYRITIC.—A term applied to aggregates of porphyritic crystals resembling the structure of plutonic rocks, but which are enclosed in groups in a volcanic type, such as dolerite or basalt.

GNEISS.—A metamorphic rock which shows a foliated, banded or gneissose structure. It may have been originally a plutonic or volcanic rock, which has been altered by subsequent shearing or even by movement before consolidation.

GRANITE.—A fairly coarse-grained, holocrystalline, plutonic rock, composed of alkali felspars, quartz, a ferromagnesian mineral, and less important accessories. Granites are found in large masses which have crystallised slowly under great pressure.

GRANITIC.—Formed of or like granite.

GRANITITE.—Biotite-granite, consisting essentially of biotite, orthoclase felspar and quartz.

GRANOPHYRE.—An intrusive igneous rock, characterised by its groundmass or matrix consisting of a microscopically fine graphic intergrowth of quartz and felspar fibres.

GRANULITIC.—Containing grains of approximately equal size, resembling a mosaic. The grains are sometimes rounded, and the structure may have been developed by movement before or after consolidation.

GRAPHIC.—A term applied to a closely associated intergrowth of two minerals, produced by their having crystallised simultaneously. Some of the resulting forms might fancifully be considered to resemble letters, hence the name. Sometimes called "granophyric."

GREENSTONE.—An old appellation for greenish diorites and diabases.

GREYWACKE.—A coarse, dark, complex sedimentary rock, consisting of fragments of quartz and other minerals or rocks cemented together.

HOLOCRYSTALLINE.—Completely crystalline, without glass or amorphous material.

HORNFELS.—A fine-grained, compact, highly metamorphic rock, the original texture of which has been completely obliterated.

HORNFELSED.—Changed to hornfels.

HOUR-GLASS STRUCTURE.—The appearance of a section at the centre of a mineral in polarised light when it shows four triangular areas meeting like the back of an envelope.

HYPABYSSAL.—A group of rocks intermediate between plutonic and volcanic. It includes intrusive and dyke rocks.

IDIOMORPHIC.—Crystals whose proper external form has been freely developed are described as "idiomorphic."

IGNEOUS.—Consolidated from a molten state.

ISOTROPIC.—Substances like glass and "cubic" crystals which have the same optical properties in every direction are said to be "isotropic."

KERATOPHYRE or CERATOPHYRE.—A variety of porphyry containing much potash-soda felspar.

METAMORPHIC.—Having the original structure altered, or new minerals formed, by the agency of heat, crushing, shearing, percolating water, or recrystallization.

MICROGRANITIC.—A microscopic form of the granitic structure, forming a groundmass.

MICROGRAPHIC.—A minute form of the graphic structure (see "GRAPHIC"). This is also known as "micropegmatite."

MOLLUSCS.—Include bivalves, snails, cuttle-fish, nautilus, &c.

OPHITIC.—When a crystal of one mineral closely wraps round, follows the outline of and encloses other previously-formed crystals of another mineral, it forms what is known as the "ophitic" structure, usual in dolerites and diabases.

OSTRACODS.—Small crustaceans with two relatively large bivalve shells.

PETROLOGY.—The science of rocks.

PHENOCRYST.—Large conspicuous crystals (in porphyritic rocks) which have formed at an earlier period than the surrounding groundmass. They probably existed under deep-seated conditions before the whole mass poured out as a lava.

PHOTOMICROGRAPH.—A photograph of the magnified image of an object in the microscope.

PLAGIOCLASTIC.—Descriptive of the varieties of felspar known as plagioclase.

PLEOCHROIC.—Showing different colours when polarised light traverses it in different directions. Pleochroism.

PLUTONIC.—Having consolidated at great depths, and therefore under conditions of enormous pressure and slow cooling. Plutonic rocks are always holocrystalline and typically non-porphyritic.

POLARISED LIGHT.—Ordinary light is considered to vibrate in all planes transversely to the direction of the ray. Polarised light, on the contrary, consists of vibrations all in one plane. For petrographical purposes light is polarised by means of a Nicol's prism placed under the stage of the microscope (polariser) and another above the object glass (analyser).

POLYZOA.—Minute jelly-like animals with horny and calcareous skeletons, which by a process of budding produce compound colonies resembling plants or corals.

PORPHYRITE.—Porphyry containing a soda-lime felspar.

PORPHYRITIC.—Resembling porphyry in structure. Pertaining to porphyry.

PORPHYRY.—An igneous rock characterised by comparatively large porphyritic crystals or phenocrysts (generally of soda-potash-felspar) in a finer groundmass of felspar, quartz, &c.

Glossary of Technical Terms.

PSEUDOMORPH.—A mineral which has the external crystalline form properly belonging to a different mineral. It is formed by the original particles being gradually replaced by those of another mineral by a slow chemical change which has left the old form intact.

PYROXENES.—A group of minerals, including augite, enstatite, diallage, &c.

QUARTZITE.—A rock composed almost entirely of closely-fitting quartz grains, and distinguished from sandstones by the cementing material being itself quartzose. It is formed by the induration of a sandstone with a siliceous cement.

RHOMBOHEDRON.—A solid having six similar rhombic faces.

SACCHAROIDAL.—Crystalline granular structure, like lump sugar.

SAGENITIC.—An arrangement of needle-like crystals (of rutile), crossing each other at angles of 60°.

SCHILLERISED.—Having microscopically fine crystals regularly deposited in definite directions. The result to the naked eye is a peculiar iridescent lustre.

SCHISTOSE.—Composed of or resembling schist. A metamorphic rock with finely laminated or foliated structure produced by shearing.

SECONDARY.—As applied to minerals. Refers to those replacing other original constituents.

SEGREGATION.—An assembling or collecting together of certain minerals in cavities or fissures, or in the solid rock, thus forming veins, &c., differing in texture or composition from the rest of the rock.

SILICEOUS.—Composed of or containing silica.

SKELETONS.—Elementary and incomplete crystal growths, generally assuming feathery or parallel forms; resembling frost flowers on a window pane.

SPHERULITIC.—Containing spherical stellate or radiate groups of minute needle-shaped crystals.

TRACHYTE.—A volcanic lava characterised by alkaline felspar, without quartz, but usually also with biotite, augite, &c.

TWINNING.—Twinned crystals are built up of two or more parts, with definite geometrical relationships according to certain laws of twinning.

VERMICULAR.—Tortuous, worm-like.

VESICULAR.—Containing minute cavities or bubbles.

WHINSTONE.—A term loosely applied to any dark, hard, fine-grained rock.

ZEOLITES.—A family of minerals of secondary origin. Some crystallise, in hair-like tufts, filling cavities and veins in igneous rocks.

ZONAL.—A concentric banded appearance in a crystal parallel to its boundaries.

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APPENDIX.

SUPPLEMENTARY TABLE

. . OF . .

ADDITIONAL ATTRITION TESTS.

NOTE.—These additional Attrition Tests have not hitherto been published.

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SUPPLEMENTARY TABLE OF ATTRITION TESTS.

Reference number.	Description of Stone.	Quarry or locality.	Hand (H) or Machine (M) broken.	Chips. Percentage detached from parent stones. Dry test.	Chips. Percentage detached from parent stones. Wet test.	Dust. Percentage of loss. Dry test.	Dust. Percentage of loss. Wet test.	Dust. Percentage of loss. Average.	Specific gravity.
		Plutonic Rocks.							
140	Quartz diorite ...	Markfield Quarry, near Leicester	—	·05	·10	5·52	6·74	6·13	2·86
		Hypabyssal Rocks.							
142	Quartz porphyrite...	Quenast, Belgium	—	·39	·44	4·54	6·40	5·47	2·73
169	„ „ („ Craigmuschat granite")	Craigmuschat, Gourock, near Glasgow	M	·0	·0	4·49	8·40	6·44	2·62
199	Quartz porphyrite...	Croft, Leicestershire	—	·0	·0	5·91	8·20	7·05	2·69
213	„ syenite („ Charnwood granite")	Charnwood Quarries, near Loughborough	M	·0	·0	6·05	8·01	7·03	2·96
148	Porphyritic quartz felsite („ Ceiriog Pandy grey macadam")	Ceiriog Pandy Quarry, Chirk, Denbighshire	H	·0	·0	4·40	4·10	4·25	2·63
173	Felsite	Cairngryffe Quarry, Pettinain, Lanarkshire	H	·78	·0	2·73	2·54	2·64	2·58
174	„	„ „ „	M	2·93	·0	3·47	2·64	3·05	2·58
178	„	Hillend Quarry, Lesmahagow, Lanarkshire	M	·88	·68	7·13	10·65	8·89	2·56
172	Granophyre ...	Llangynog Quarry, 14 miles W. by S. of Oswestry, Montgomeryshire	M	3·12	·0	3·71	5·66	4·69	2·67
146	Quartz - enstatite diabase	Penmaenmawr, Carnarvonshire ...	H	·0	·0	3·12	4·78	3·95	2·81
147	„ „	„ „ „	H	·0	·0	3·81	5·37	4·59	2·79
149	Coarse green diabase („ Ceiriog Pandy grey granite")	Ceiriog Pandy, Chirk, Denbighshire	M	2·25	·49	10·10	16·90	13·50	3·02
207	Diabase („ Hendre blue stone")	Hendre Quarry, Llansilin, Denbighshire	H	·0	·0	5·66	12·16	8·91	2·92
160	Quartz diabase ...	Broomknowe Quarry, 2½ miles S. of Cupar, Fife	H	·0	1·32	15·43	39·60	27·51	2·77
193	Diabase („ Porthgain granite")	Porthgain, N. of Llanrheian, Pembrokeshire	—	·0	·0	6·20	9·47	7·84	2·80
143	Epidiorite	Trentagh Quarry, St. Johnston, Co. Donegal	M	·10	·0	5·57	11·52	8·54	3·04
171	„ („ Elvan")	Porthoustock, St. Keverne, Cornwall	H	·0	·0	3·42	5·81	4·61	2·91
		Volcanic Rocks.							
170	Trachyte or keratophyre	Coed-y-Glyn Quarry, Glyn Ceiriog, Denbighshire	M	·54	·0	3·37	7·76	5·57	2·82
206	„ „ „ („ green granite")	Pandy Quarry, Glyn, near Chirk, Denbighshire	—	·0	·0	2·83	5·52	4·17	2·83

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Supplementary Table of Attrition Tests.

Reference number.	Description of Stone.	Quarry or locality.	Hand (H) or Machine (M) broken.	Chips. Percentage detached from parent stones. Dry test.	Chips. Percentage detached from parent stones. Wet test.	Dust. Percentage of loss. Dry test.	Dust. Percentage of loss. Wet test.	Dust. Percentage of loss. Average.	Specific gravity.
		VOLCANIC ROCKS (*continued*).							
209	Trachyte or keratophyre ("green granite")	Bridgend Quarry, Rossie, Auchtermuchty, Fife	H	·0	2·49	4·40	7·37	5·88	2·64
210	" " ...	" " " " ...	M	·78	·39	5·66	9·72	7·69	2·64
186	Trachyte or keratophyre	Coed-y-Glyn Quarry, Glyn Ceiriog, Denbighshire	—	·0	·0	3·66	7·08	5·37	2·80
161	Hyperstbene andesite (altered)	Forret Quarry, 3½ miles N. by E. of Cupar, Fife	H	4·30	·0	9·18	17·72	13·45	2·65
162	" " ...	" " " ...	M	·83	·0	9·72	15·43	12·57	2·76
165	Andesite ("Arenig stone")	1 furlong S. of Arenig station, G. W. Ry., Merionethshire ...	H	·0	·0	4·15	5·27	4·71	2·70
166	" "	" " "	M	·0	2·25	5·47	5·57	5·52	2·68
151	Olivine basalt ...	Carriston Quarry, Markinch, Fife	H	·0	·0	5·56	10·55	8·10	2·84
155	" ...	Langside Quarry, Kennoway, Fife	H	3·47	·0	11·28	17·97	14·62	2·23
156	" ...	" " "	M	·93	4·78	7·62	14·06	10·84	2·83
157	" ...	Pitcairn Quarry, Markinch, Fife	H	·0	·0	6·74	10·74	8·74	2·90
158	" ...	" " "	M	·49	4·10	9·47	12·55	11·01	2·47
159	" ...	Stenhouse Quarry, Burntisland, Fife	H	4·49	3·03	7·42	9·62	8·52	2·94
179	Olivine basalt ("green granite")	Craig Cwlwm Quarry, Porth Pistill, Aberdaron, Carnarvonshire	—	·0	·0	8·89	13·87	11·88	2·89
181	Olivine basalt ("Steelend granite")	Steelend Quarry, Steelend, near Saline, Fife	H	·0	·0	4·35	5·76	5·05	2·90
175	Porphyritic dolerite	Kersewell Quarry, Carnwath, Lanarkshire	H	·39	·0	4·79	10·30	7·54	2·83
176	" "	Craighead Quarry, Crawfordjohn, Lanarkshire	H	3·08	·0	5·62	8·06	6·84	2·98
134	Ophitic olivine dolerite	Freehall Quarry, Castlerock, Co. Londonderry (bottom of quarry, S. end)	M	·0	·0	8·40	21·88	15·14	2·93
135	" "	Freehall Quarry, Castlerock, Co. Londonderry (top of quarry, N. end)	H	·0	·10	8·30	15·04	11·67	3·04
136	" "	Freehall Quarry, Castlerock, Co. Londonderry (bottom of quarry, N. end)	H	·0	·83	8·60	22·61	15·60	2·90
137	" "	Freehall Quarry, Castlerock, Co. Londonderry (top of quarry, N. end)	M	·10	·15	5·61	14·79	10·20	3·01
138	Ophitic olivine dolerite (not so fresh as No. 137)	Freehall Quarry, Castlerock, Co. Londonderry (bottom of quarry, S. end)	M	·0	·0	8·20	15·92	12·06	2·93
152	Ophitic olivine dolerite	Galliston Quarry, Kirkcaldy, Fife	H	·0	·0	8·89	12·30	10·60	2·98
163	" "	Percy Baldinnie Quarry, 4 miles S.E. of Cupar, Fife	H	·0	·0	10·74	24·85	17·80	2·94
164	Ophitic olivine dolerite (altered)	" " "	M	·0	·0	12·69	24·32	18·50	2·86

Supplementary Table of Attrition Tests.

Reference number.	Description of Stone.	Quarry or locality.	Hand (H) or Machine (M) broken.	Chips. Percentage detached from parent stones. Dry test.	Chips. Percentage detached from parent stones. Wet test.	Dust. Percentage of loss. Dry test.	Dust. Percentage of loss. Wet test.	Dust. Percentage of loss. Average.	Specific gravity.
		VOLCANIC ROCKS (*continued*).							
150	Olivine dolerite ...	Auchterderran Quarry, Cardenden, Fife	M	·0	·0	7·95	15·09	11·52	2·89
153	„ „ ...	Gleneraig Quarry, Lochgelly, Fife	M	·39	1·46	6·25	14·35	10·30	2·81
154	„ „ ...	Kilrie Quarry, Kirkcaldy, Fife ...	H	·88	1·66	8·50	18·36	13·43	2·79
191	„ „ ...	Clee Hill Dhu Quarries, Clee Hill, Ludlow, Shropshire	—	·0	·0	6·84	11·13	8·99	2·81
192	„ „ ...	Titterstone Quarries, Clee Hill, Ludlow, Shropshire	—	·0	·0	4·69	8·59	6·64	2·89
167	Dolerite ("Hafotty stone")	1 mile W.S.W. of Arenig Station, G.W.Ry., Merionethshire ...	H	·0	·0	5·08	10·84	7·96	2·89
168	„ „	„ „ „	M	·0	·0	7·03	12·01	9·52	2·89
177	Dolerite	Stoneyburn Quarry, Crawford, Lanarkshire	H	·0	1·95	5·71	10·45	8·08	2·84
141	Volcanic breccia ...	Bardon Hill Quarry, Leicestershire	—	·10	·0	3·81	7·62	5·71	2·80
212	Dacite Tuff ("Forest Rock granite")	Houghton Hill, Whitwick, Leicestershire	M	·0	·0	7·03	8·54	7·79	2·84 to 2·87
		SEDIMENTARY ROCKS.							
187	Quartzite	Smith's Quarry, 1 mile from Pontesbury Station, Shropshire	—	·0	2·83	6·20	8·79	7·50	2·60
188	„	Pugh's Quarry, 1 mile from Pontesbury Station, Shropshire	—	·0	2·20	5·86	9·42	7·64	2·58
189	„	Granham Moor Quarry, Habberley, near Pontesbury, Shropshire ...	—	1·71	·0	7·08	9·03	8·06	2·59
197	„	Quarry "A.," Wick, Gloucestershire	H	·0	·0	3·13	4·98	4·05	2·56
198	„	Quarry "B.," Wick, Gloucestershire	H	·0	·0	3·32	4·69	4·00	2·62
190	Grit	Cornes' Quarry, Sharpstones, 2 miles S. of Shrewsbury	—	1·32	2·05	9·18	13·72	11·45	2·78
139	Impure sandstone ...	Ynismendwy, near Pontardawe, South Wales	H	·0	·0	6·25	18·02	12·13	2·69
200	Indurated shale ...	Colfin Quarry, Wigton ...	H	2·25	·0	8·50	15·14	11·82	2·70
201	„ „	„ „ ...	M	·0	·0	9·47	16·02	12·74	2·67
202	Partly silicified, gritty shale	Balgreggan Quarry, Wigton ...	H	2·05	3·17	6·15	9·86	8·01	2·78
203	„ „	„ „ ...	M	·0	1·76	8·30	10·99	9·64	2·81
204	Felspathic sandstone	Kirkland Quarry, Wigton ...	H	3·57	1·12	10·74	21·05	15·89	2·69
205	„ „	„ „ ...	M	·0	·0	14·16	22·51	18·33	2·72
208	Micaceous sandstone	Myddleton Quarry, Glyn, near Chirk, Denbighshire	—	·0	·63	6·93	12·65	9·79	2·72
183	Dolomite	Cwm Quarry (top bed), near Abergavenny, Monmouthshire ...	H	·0	1·07	10·99	16·60	13·79	2·78
184	„	Cwm Quarry (bottom bed), near Abergavenny, Monmouthshire ...	H	·0	·39	12·30	18·36	15·33	2·78

Supplementary Table of Attrition Tests.

Reference number.	Description of Stone.	Quarry or locality.	Hand (H) or Machine (M) broken.	Chips. Percentage detached from parent stones. Dry test.	Chips. Percentage detached from parent stones. Wet test.	Dust. Percentage of loss. Dry test.	Dust. Percentage of loss. Wet test.	Dust. Percentage of loss. Average.	Specific gravity.
		SEDIMENTARY ROCKS (*continued*).							
180	Limestone (oolitic siliceous)	Llanelly Quarry, Clydach, near Abergavenny, Monmouthshire ...	M	·68	2·54	11·47	17·92	14·70	2·71
182	Limestone	„ „ „	H	·0	·0	7·42	14·84	11·13	2·71
185	„	Clydach Quarry (white rough bed), near Abergavenny, Monmouthshire	H	·0	1·37	15·72	30·27	23·00	2·68
194	„	Tytherington, 10 miles from Bristol, Gloucestershire	M	·0	·0	9·47	20·07	14·77	2·66
195	„	Southmead Quarry, Bristol ...	M	·0	1·37	7·42	10·94	9·18	2·74
196	„	Abbots Leigh Quarry, Bristol ...	M	2·83	·44	10·55	23·68	17·11	2·70

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